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16. ABSTRACT

This report covers a period from April 16, 1979 - May 3, 1979. The project described herein, "Cooperative Agreement for the Evaluation of Current Environmental Research and Establishment of Priorities", had the following objectives; to evaluate the adequacy of current environmental research in relation to future anticipated regulatory decisions and budgetary planning; and to establish priorities for funding environmental research and development appropriate to public health initiatives. At a series of meetings, invited scientists addressed specific environmental and public health issues; Management - Conservation; Measurement and Analysis; Source Characterization and Control; Human Exposure, Effects, and Monitoring; and Environmental Processes, Effects, and Monitoring. Six member working committess presented officials in the EPA Office of Research and Development with information utilized in preparing the Fiscal Year 1981 budget. A second meeting was then convened to discuss and develop responses to questions raised by EPA officials. This document includes the reports of the 20 committees which met for the first series of meetings, the questions raised by EPA officials, and the reports of the the follow-up meeting, prepared in response to the questions.

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INTRODUCTION

The report that follows was prepared as the result of a Cooperative Agreement between the U.S. Environmental Protection Agency, Office of Research and Development, and The Pennsylvania State University, Program in Health Planning and Administration. The project, "Cooperative Agreement for the Evaluation of Current Environmental Research and Establishment of Priorities," ran for the period from March 8, 1979 to October 31, 1979, with the following objectives:

(1) To evaluate the adequacy of current environmental research in relation to future anticipated regulatory decisions and budgetary planning.

(2) To establish priorities for funding environmental research and development appropriate to public health initiatives.

The approach used to obtain these objectives was to convene a series of meetings of invited scientists to address specific environmental and public health issues, listed below. These areas of concern were agreed upon after meetings between EPA and Penn State scientists:

MANAGEMENT-CONSERVATION

Ecosystem Management
Environmental Impact
Ecosystem Restoration
Economic Solutions

MEASUREMENT AND ANALYSIS

Exposure of Human Populations and the Environment
Measurement and Analysis: Biological Monitoring
Measurement and Analysis of Sources and Ambient Levels

SOURCE CHARACTERIZATION AND CONTROL

The Ultimate Disposal Aspects of Environmental Protection
Incentives and Framework for Control
Source Characterization
Separation and Treatment Technology
Process Change-Product Substitution

HUMAN EXPOSURE, EFFECTS, AND MONITORING

Cardiovascular and Chronic Disease
Neurological Effects and Behavioral Toxicology
Teratogenic and Reproductive Effects
Carcinogenesis and Immunologic Effects

ENVIRONMENTAL PROCESSES, EFFECTS, AND MONITORING

How, What, Where, and In What Form
Critical Terrestrial Ecosystems: Land and Air
Critical Ecosystems: Water
The Atmosphere As a Critical Ecosystem

These working committees generally had six members, with the preferred ratio being two Penn State University scientists, two EPA scientists, and two scientists from other universities or research institutes throughout the country. (The members of each committee are listed at the beginning of each report throughout this document.) All committees met for two days on the campus of Penn State University, in University Park, Pennsylvania, between April 16 and May 3, 1979.

The reports prepared by these committees were then transmitted to officials in the EPA's Office of Research and Development, who reviewed them and utilized the contents in the preparation of the Fiscal Year 1981 budget. In addition, the EPA officials also raised some questions for further discussion and elaboration. These questions were then transmitted to all participants in the April-May meetings in order to obtain their responses. A second meeting was then convened, to which 21 of the original group of participants were invited, in order to discuss and develop responses to the questions raised by the EPA officials. This meeting was held on the Penn State campus during late June 1979. The participants in the second meeting were selected for their expertise in the specific areas where questions had been raised.

This document includes the reports of the 20 committees who met for the first series of meetings, the questions raised by EPA officials, and the reports of the follow-up meeting, prepared in response to the questions raised by the EPA officials. Also included are the names and affiliations of all consultants who participated in the project.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

Workshop Topics

MANAGEMENT-CONSERVATION

Ecosystem Management	April 26-27, 1979
Environmental Impact	April 26-27
Ecosystem Restoration	April 26-27
Economic Solutions	May 2-3

MEASUREMENT AND ANALYSIS

Exposure of Human Populations and the Environment	April 16-17
Measurement and Analysis: Biological Monitoring	April 17-18
Measurement and Analysis of Sources and Ambient Levels	April 23-24

SOURCE CHARACTERIZATION AND CONTROL

The Ultimate Disposal Aspects of Environmental Protection	April 23-24
Incentives and Framework for Control	April 23-24
Source Characterization	April 23-24
Separation and Treatment Technology	April 26-27
Process Change-Product Substitution	April 26-27

HUMAN EXPOSURE, EFFECTS, AND MONITORING

Cardiovascular and Chronic Disease	April 20-21
Neurological Effects and Behavioral Toxicology	April 23-24
Teratogenic and Reproductive Effects	April 24-25
Carcinogenesis and Immunologic Effects	April 24-25

ENVIRONMENTAL PROCESSES, EFFECTS AND MONITORING

How, What, Where, and In What Form	April 24-25
Critical Terrestrial Ecosystems: Land and Air	April 24-25
Critical Ecosystems: Water	April 26-27
The Atmosphere As a Critical Ecosystem	April 26-27

COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

Ecosystem Management

April 26 and 27, 1979

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ECOSYSTEM MANAGEMENT

I. Introduction

The Ecosystem Management Committee began its work with the understanding that the U.S. Environmental Protection Agency's mission is to protect and enhance environmental quality. We also understand that research is not its primary mission except to the extent that the Agency requires research, development, and demonstration to support its regulatory role and to help it anticipate future environmental problems and research needs.

It also seems to us that, except by influence from the various regulations it has issued and the standards it has set, the Agency has never developed an operational definition of its mission. Yet such a definition is an essential first step, both for the Agency to assess its success in achieving its assigned mission and for this Committee to accomplish the task it has been assigned. To identify ecosystems management research needs and to set research priorities, we have assumed that environmental protection can be operationally defined in terms of environmental values and management objectives and processes. We have also assumed that environmental values and management objectives and processes can be divided into at least two categories: those that relate to the maintenance of ecosystem functions and structure, and those that relate to societal preferences (Andrews & Wait, 1978). The first category consists of those values that would maintain natural systems as they are--for example, an expressed value to maintain the current CO_2 balance in the atmosphere or to preserve the nation's wetland areas. To achieve the first goal, the EPA would have to restrict CO_2 emissions to a minimum level; to achieve the second, it would restrict dredging and filling in wetland areas.

The second category of values and objectives consists of those that specify the limits of ecosystem changes society is willing to accept in order to achieve other values. Kenneth Boulding (1978) contends that societal values should be considered a component of ecosystems. For example, society may prefer to accept some degree of climate change rather than forego certain activities that exacerbate the CO_2 problem; or society may prefer to accept some degree of dredging and filling of wetland areas in order to provide more farmland.

We should pay more attention to describing the Agency's mission in relation to these two categories. An operational definition is, therefore, essential to the development of an adequate theory or conceptual framework to identify and guide the evaluation of research needs and to set research priorities. The Committee believes that the formulation of some such definition should be assigned a high priority.

To achieve its operationally defined mission, the EPA must be able to anticipate the consequences of its actions on the environment; to know what actions are likely to protect and promote specific environmental values; and how, to the maximum extent possible, to ensure that its present and planned activities do not limit future options. To accomplish these tasks, the EPA must consider itself an ecosystem manager. Although there may be several theories or conceptual frameworks that might be useful to the Agency in this regard, the Committee believes that the body of theory generally referred to as systems ecology is particularly promising. It offers a set of concepts that can guide the integration or synthesis of existing knowledge. This knowledge base can inform ecosystem management and help to identify research needs and priorities.

Furthermore, in regard to the identification of research needs and priorities, the Committee strongly believes that ecosystem management involves a nontraditional view of management. Ecosystems management is directed toward what would be required to sustain ecosystems so that they can continue to deliver desirable goods and services. This point of view contrasts with the more traditional view of management in which management focuses directly upon the production of goods and services per se.

II. The Committee's Conceptual Framework

A Committee that addresses the concept of ecosystem management should briefly discuss the concept "ecosystem." We have loosely defined an ecosystem as a unit of physical space containing mutually interacting abiotic and biotic components, including self-regulating mechanisms. An ecosystem can include a human component. But in any attempt to deal with an ecosystem, one must create a simplified abstraction of that ecosystem because one cannot retain a perfect representation in the mind. Furthermore, the degree of simplification and abstraction is very much a function of the observer's interests and objectives.

Thus, the conceptual ecosystem is a necessary simplification; therefore, any attempt to apply a measurement or analysis of ecosystem behavior to real-world sites may be subject to uncertainty. Often, especially with certain well-defined systems, the uncertainty itself can be estimated, but uncertainty usually increases with complexity of the system.

The selection of temporal resolution of the measurements, models, and analyses, and the determination of system boundaries are decisions reflecting the interests of the observer and his goals. The site of interest may range in size from the Mississippi-Missouri River Basin, to New York City, to Florida's Big Cypress Swamp, to a single small watershed, to an agricultural field, or to a small pond. The conceptual ecosystem must be consistent in resolution with the properties and behavior of the physical sites. The choice of the temporal resolution is important. And, in general, the smaller the object (site), the finer the temporal resolution should be.

All ecosystems can be divided into successively smaller subsystems (or components). In general, ecosystems can be aggregated into edaphic, atmospheric, biotic, and human subsystems. Couplings between the subsystems can be thought to represent processes, flows, or interactions, depending on the interests of the observer.

These ecosystem components and attributes are not always easy to measure or quantify. Furthermore, many of the attributes that are improtant to the observer may have no common denominator. Managers are often required to balance economic, biotic, and aesthetic values. This is the problem of noncommensurate variables: How do we deal with apples and alleycats?

Other aspects of ecosystems should be mentioned. The dynamic (time-varying) nature of the processes within the system can lead to changes of system quantities. In addition, the very structure of the system itself can change: New components and linkages can appear and disappear, especially in ecosystems that include a large human component. How do we deal with the dynamic nature of ecosystem structure?

Finally, man has not yet learned to think on an ecosystem basis. An individual is part of the human subsystem. It is easier to perceive and deal with systems at a lower level of aggregation (organ systems, microcosms, single organisms) than to deal with the systems of which we are a part. Thus, we have a need to develop holistic or macro experimental protocols as well as micro protocols. As an analogy, the liver would find it hard to understand how its activity coupled with that of the heart and kidneys would affect the body as a whole.

Ecosystem resilience is due in part to self-regulation. This resilience varies among ecosystems and is an important consideration in ecological management, especially with regard to the limits (called "persistence limits") beyond which an ecosystem can be perturbed and still recover.

Attempts to understand and analyze ecosystems have led to the development of ecosystem models presented in various forms--for example, systems of differential equations, Markov chain models, graphical representations, and simplistic regression models. Systems analysis has met with varying success, but the approach is in its infancy.

III. Research Needs and Priorities

The Committee has divided its recommendations concerning research needs and priorities in ecosystem management into five lettered categories: (A) Conceptual Framework and Theory Development; (B) Analytical Methods and Technique Development; (C) Data and Data Management; (D) Organizational and Institutional Factors; and (E) Additional Organization Research Recommendations. Each of these categories is discussed in turn.

This order of presentation does not necessarily reflect any specific emphasis the Committee placed on the five categories. Recommendations appear within each category and are numbered sequentially, 1 through 29, throughout all five of the lettered categories. Some of these recommendations appear with sub-headings, and some are delineated only by their respective number.

The Committee suggests that the EPA concentrate first on the priorities that fall within its domain and then encourage other, appropriate organizations to undertake the research related to the remaining recommendations.

A. Conceptual Framework and Theory Development

A complete, unambiguous understanding of ecosystem theory is not yet a reality. Nor do most managers have a well-grounded understanding of the nature of systems in general and ecosystems in particular.

(1) Consequently, the Committee recommends that the EPA encourage attempts to investigate the general nature of ecosystems. Specifically, research is needed in the following general categories:

(2) Ecosystem theory. We must clarify the ecosystem paradigm in a qualitative conceptual sense. Examples of this approach would include the work of Overton and his colleagues (Overton, 1977; Overton & White, 1978), and certain other attempts to apply general systems theory to ecological concepts.

(3) Mathematical techniques. We must continue to develop existing mathematical techniques. Examples in this category would include the work of Odum and his colleagues (Hall & Day, 1977) and other practitioners of the engineering systems approach. The EPA should encourage investigation into the possible applications of such mathematical disciplines as group theory or combinatorics to ecological problems. It should also encourage investigations into methods of dealing with noncommensurate variables and dynamic system structure.

(4) The problem of scale. Methodologies exist for analyzing microcosms and small-scale ecosystems. These analytic techniques have often followed the development of certain instruments or measurement protocol. We have a need to develop techniques and protocols for dealing with large or highly aggregated systems.

One member of the Ecosystem Management Committee, Sandra Brown, contributed a "Minority Report" for section III A. (Conceptual Framework and Theory Development) of the Committee's Final Report. Her remarks follow here:

Government policies and management schemes must be based on a strong ecosystem conceptual background. Yet, while it is true that governmental agencies are entrusted to manage entire ecosystems, many of their current policies and most of their managers fail to reflect holistic thinking. Consequently, the EPA should encourage attempts to investigate the structural and functional characteristics of ecosystems. More specifically, the Agency should concentrate on research in the following general categories:

(a) unifying principles of ecosystem organization and function along the lines of those developed by E. P. Odum in the 1971 edition of his classic ecology textbook;

(b) types and rates of ecosystem succession;

(c) ecosystem responses to human-induced and natural stress;

(d) techniques for ecosystem restoration and stress mitigation; and

(e) the nature and intensity of ecosystem coupling on a regional scale.

An example of the last type of study is the Hubbard Brook Watershed Study conducted by Likens, et al. (1970).

In supporting these research projects, the EPA should encourage the use of quantitative and experimental work under field conditions. Such research techniques as remote sensing, computer modeling, and the mathematical manipulation of data could prove to be valuable research tools, but they should not be funded as research subjects in themselves. Esoteric research should not be a priority of a regulatory agency like the EPA; it should be left to such governmental agencies as the National Science Foundation and the National Academy of Sciences.

B. Analytical Methods and Techniques

The Committee intends its analytical methods and techniques research recommendations to encourage integrating-synthesizing research to inform the EPA's management of ecosystem behavior. Specifically, these recommendations are aimed at (a) improving the Agency's ability to characterize present ecosystem-level problems and develop solutions; and (b) improving the Agency's ability to anticipate future environmental problems and identify and define the research the Agency needs either to avoid or to mitigate these problems.

(5) Characterizations. The Committee sees a need to characterize present ecosystem problems. We believe that better analytical techniques are needed to characterize the structural and behavioral aspects of various ecosystems,

much like the ecosystem characterizations that the U.S. Fish and Wildlife Service has developed for coastal ecosystems. Such approaches identify for management the important driving forces and most sensitive ecological linkages. They also help make the decision process more efficient, since critical relationships are identified early and resources can be allocated to study the least understood or most recalcitrant systems and problems.

(6) Optimization and decision making. Since various numerical techniques are now available for goal programming, the Committee believes that the application of modeling and simulation techniques to provide information on optimal choices in ecology should be encouraged. We need both basic and applied research in this area, and the improvement and application of decision theory would be helpful.

Since systems are often more sensitive to one component than another, sensitivity analysis is a useful analysis and decision-making procedure. Given a problem, one could model the system on available knowledge. The model could be exercised and the components contributing most to the behavior identified. These components would be the logical foci of research, were insufficient funds or temporal constraints to preclude a study of the whole system.

(7) Spatial information. Much of the information needed by managers resists the engineering systems approach. Often, the spatial distribution of ecosystem components is as important as the identification of the fluxes and couplings. But spatial information systems are emerging where mapping algebras encourage analyses of spatial data. The Committee suggests that the coupling of economic and mechanistic models to mapping algebras promises a relatively high degree of success.

(8) Anticipatory forecasting and future research. The Committee agrees with the recommendations on Environmental Forecasting and Technology

Forecasting made in Chapter 8 of Volume 2 of the HEW Human Health and the Environment report. In this regard, we believe that the EPA should concentrate on improving its ability

(a) to make credible projections of the relative quantities of pollutants likely to be introduced into the environment given a range of alternative economic, energy, and environmental policies;

(b) to analyze the likely consequences of the introduction of these quantities of pollutants into the environment and identify the alternative ecosystem strategies; and

(c) to identify and define the research the Agency should undertake to be able to manage the ecosystem and its goods and services;

Four specific recommendations for EPA support follow here:

(9) The EPA should support the critical evaluation and further development of environmental and technology forecasting and assessment methods. Promising forecasting and assessment tools should be systematically tested and applied, with an emphasis on using these methods and techniques to synthesize and integrate research results so as to facilitate ecosystems management.

(10) The EPA should develop additional and alternative environmental assessment models and analytical techniques, such as materials flow and process alternatives, to its present, predominantly formal, economic models approach.

(11) The EPA should develop better methods for assessing risks and determining health effects, materials damages, and a broad range of ecosystem consequences.

(12) The EPA should develop a system for identifying and assessing the significance of future environmental problems and opportunities, including environmental indicators and indices for detecting and "measuring" environmental quality changes, and participation mechanisms that provide the Agency with the benefits of both expert knowledge and public perceptions.

C. Data Needs and Data Management

(13) Data needs. Many of the waste products of human activity, like air pollutants, solid wastes, and liquid wastes, are disposed of in our natural environment, and exert a variety of effects on the environment. The severity with which the products of human activity impact the environment may be related to the part of the ecosystem that is affected and to the intensity of the stress (Lugo, 1979). For example, human intervention that alters an energy inflow into a system may have a more serious effect on the ecosystem's structure and processes than an impact affecting the animal or microbial component. But we understand comparatively little about ecosystem response to known intensities of different stressors. In order for society to continue to derive services from natural resources, the EPA must concern itself with how our natural resources respond to an array of human impacts, whether applied singly or collectively.

Some ecosystems are more tolerant of human impact than others. For human systems to meld better with natural systems, we need to identify those ecosystems that are compatible with human wastes. For example, some research has shown that wetland ecosystems act as natural filters for domestic sewage effluent (Odum & Ewel, 1977). Other natural ecosystems may tolerate other kinds of human wastes and experience little or no adverse effect.

(14) When determining which ecosystems are better adapted to receiving products of human activities, we must ascertain the long-term effects. Therefore, the EPA must concern itself with long-term research projects that address these effects.

To determine the effect of man's activities on natural ecosystems, we need a broader data base covering the functional and structural characteristics of natural ecosystems. But before we collect these data, we should formultate a conceptual model of the system (a variety of methods appears in Hall & Day, 1977) to ensure that we identify the important processes and structural components. The processes might include nutrient cycling, productivity, and decomposition; the structural components might include biomass, edaphic characteristics, and species diversity. The Committee stresses, however, that the data collected should be integrated to produce a better understanding of our natural environment.

(15) Human action applied to one ecosystem may have an undesirable impact on other ecosystems downstream. In order to be able to predict these effects, we need more data to determine the types and the magnitudes of various ecosystem couplings. For instance, what is the effect of runoff from agricultural land carrying various biocides on the receiving water bodies? or what effect does the filling of riparian wetlands have on downstream human settlements? For EPA to accomplish its goals effectively, it should have the answers to these kinds of questions.

Ecosystems management concerns extend increasingly to human impact within ecosystems. More specifically, societal patterns of resource extraction, production, distribution, and consumption, and patterns of collective decision making and social control all affect ecosystem conditions. The values, attitudes, incentives, and constraints that direct societal behavior in these activities are basic to ecosystem management. Societal values and attitudes can govern a wide variety of environmentally related behavior--and on a broad scale. The role of values and attitudes in societal behavior that affects ecosystems is not adequately understood, nor has the susceptibility to change of these values and attitudes been adequately researched. Incentives and constraints are often introduced intentionally to govern or modify specific behavior within specific circumstances. Consideration of the range and mix of incentives and constraints applied to environmental production purposes has generally been eclipsed by an emphasis upon formal regulation and compliance strategies.

(16) Consequently, the EPA should encourage research that focuses upon values and attitudes supporting societal patterns of behavior affecting ecosystems and upon the extent to which these values and attitudes are subject to change. The Agency should also encourage research into the effectiveness of a variety of incentives and constraints designed to modify individual and collective decisions on environmental concerns.

Data management. Ecosystem management should also be based on the best possible data bases. Such information exists in the professional literature and in various other areas. Information in the professional literature is usually retrievable. In addition to the more formal sources, however, research and data collection are often performed by such other federal agencies as the U.S. Department of the Interior, the U.S. Department of Agriculture (USDA), and the U.S. Department of Health, Education, and Welfare. Much of this research resides "in house."

The Committee considers the U.S. Environmental Protection Agency as the primary integrative organization within the United States government for environmental concerns. The USDA, for example, takes responsibility for the agricultural environment, but tradeoff decisions between agricultural productivity and protection of the public at large (as well as birds, insects, and other wildlife) resides with the EPA. In a similar manner, the U.S. Department of Interior has a strong concern for fostering wildlife survival, especially on federal lands, but the ultimate responsibility for the total ecosystem of a region remains with the EPA.

(17) Therefore, the Committee recommends that the EPA foster cooperative research with other federal agencies to obtain the data essential to sound ecosystem management. Similarly, the EPA should develop cooperative retrieval systems so that the information that already exists or is being generated

by ongoing programs can be used by the EPA in ecosystem management decisions. Interagency distrust is a traditional problem here, and the Committee urges the EPA to make a conscious effort to break down these barriers.

D. Organization and Institutional Factors

Structure and research management. The organizational structure of the EPA will affect decisions on research planning and budgeting as well as the use and interpretation of research results. The Committee recognizes that the EPA is not a research institution, but is rather an integrative regulatory agency with broad responsibilities for environmental protection. Knowledge generated by research is crucial to this function. The EPA must have access to research results and other kinds of information, not only from in-house efforts, but also from the entire scientific community. Moreover, the information employed in this process must be scientifically reputable and available for open criticism.

Research priorities and the research projects proposed as a result may emerge from a variety of public pressures and perceived informational needs. Neverthless, the EPA must make certain that its assessments and resulting priorities follow a plan that enables it to fulfill its integrative mission. The EPA's internal organizational structure should provide mechanisms for conducting the integrative, aggregative research essential for macro ecosystems analysis and management. Similarly, this internal structure must provide the mechanism for open and frequent consultation with the scientific communities found in public universities, private research institutes, and other governmental agencies.

(18) Therefore, the EPA should join with the rest of the research community in developing conceptual frameworks that lead to the kind of research that informs priority setting and project planning. Regular participation by outside peer scientists can help maintain the quality of and provide

direction for the EPA research units. A free interchange within the environmental science community must be fostered and maintained, and the EPA must form a partnership with this community. This partnership could take various forms, but it must be broad-based and involve numerous scientists and institutions. A "scientific advisory panel" is not the answer. The Committee envisions an interactive association resembling the USDA and the land grant university experiment station agricultural research network.

Organizing large-scale research. We also need the kind of extensive studies that adequately address integrative and aggregative research needs. Too often, such projects suffer from poor organization design within the project, or from inadequate linkages between the various research units. With the increasing costs of extensive research projects and in view of the limited funds available for research, managerial problems require immediate attention.

(19) Consequently, the Committee recommends an analysis of the previous and ongoing EPA-funded research projects to determine optimal project organization approaches and best linkages between the EPA and research project units.

Research utilization for organizational decisions. The Committee considers the utilization of research findings in setting the EPA's standards and priorities and in guiding other management decisions an important objective. One of the specific barriers in this area, though, is the lack of adequate techniques to aid in synthesizing macro and micro ecosystem research.

These decisions are too frequently based on a narrow-to-broad translation (that is, micro experimental findings are generalized to a global level) and are further operationalized on a general-to-specific basis (that is, the setting of a single standard applicable to all state and local areas, regardless of potential dangers).

(20) The Committee urges the EPA to conduct research that develops and tests techniques for synthesizing macro and micro ecosystem research findings. Techniques for "extrapolating" micro research to complement macro research in developing national standards and priorities are essential. So are techniques for "interpolating" macro research findings to variations in micro species and contexts to guide implementation.

Organizational approaches. The manner in which environmental protection organizations are organized and administered varies between national government, federal region, state government, and regional or municipal agencies, as well as among agencies at the same level of government. An illustration of the latter point is found in the fact that many state environmental agencies resemble the U.S. EPA in organizational form (they organize their offices by resource category--air, water, land, etc.); and the agencies of a few states are organized according to environmental protection functions (offices for regulation and enforcement, monitoring and testing, policy development, etc.). But we have no research that assesses the strengths and weaknesses of different organizational arrangements for achieving the goal of environmental protection.

A report of the Council of State Governments (1975) specifically supports this observation and Recommendations (21) and (22).

(21) The Committee recommends comparative research on organizational arrangements to assess variations in the operations and effectiveness of environmental agencies according to the types of organizational structure they employ. Such research should examine the legal and technical barriers to the functional integration of agency programs. Additional study might assess the potential tradeoffs between support for holistic approaches versus advocacy for specific resource categories according to organizational arrangements. Finally, research should assess the impact state agency organizational

arrangements and procedures have upon relationships with industries, regional agencies, and municipalities.

Coordination with related policies. The effectiveness of environmental protection programs depends in large part upon successful coordination with a variety of other programs and policies. More specifically, coordination might involve economic development, land use, conservation, and growth management programs or functions. Some state environment agencies encompass one or more of these additional functions while others employ interagency coordinating bodies or coordinate informally or infrequently.

(22) The Committee believes that research should focus on the success of those state and regional agencies that combine environmental protection responsibilities with such other functions as economic development, land use, conservation, and growth management, versus those agencies with responsibilities limited to environmental protection. In the same context, one might also examine the shrinking number of situations wherein health agencies exercise environmental protection responsibilities. This research should also provide insights into the appropriate location (national, state, regional, or local) for coordinating environmental programs with economic development responsibilities, with land use supervision, and with public health protection.

E. Additional Organizational Research Recommendations

(23) We need research that focuses on intervention strategies employed by the states and regions in working with communities. Specific attention should be given to a resource-by-resource approach as opposed to the multi-resource team approach.

(24) We should determine the conditions that lead agencies to place greater or lesser stress on regulations, potential funding support, and technical assistance. See Ackerman, et al. (1974) on this point.

(25) We should learn to what extent such intervention efforts consider multi-functional planning (environmental protection concerns along with concerns for development, housing, and transportation).

(26) We also need research that focuses on potential problems and opportunities for environmental protection efforts--that is to say, anticipatory research. Such research might deal with the potential effects of other national programs, societal trends, and natural disasters.

(27) With respect to national programs, we might focus on the potential environmental effects of shifting to coal to meet energy needs. In the area of societal trends, we might assess migration patterns of populations and industries as affecting environmental protection concerns. Finally, natural disasters can create environmental dangers (radiation, the breaching of toxic waste and hazardous waste stockpiles or reservoirs, or the destruction of sewer systems) and opportunities for new interventions (taking advantage of crises to accomplish environmental protection objectives, or establishing new systems, or regulating the rebuilding effort on a flood plain, for example).

(28) We need research that focuses on the crisis management capabilities of different types of environmental protection agencies. Because many years of building an effective organization can be undone by a failure to deal with a single major crisis, it is all the more important that environmental protection organizations possess fail-safe crisis management capabilities. Moreover, efforts in this area can contribute to the discovery of better ways for dealing with the day-to-day responsibilities of the organization.

(29) We need research focusing on manpower needs for environmental protection organizations at the national, federal region, state, regional, and local levels. What types of expertise and professionals are essential to the performance of the multiple functions of such agencies? To what extent do personnel limit the types of functions performed by these agencies? To

what extent do the functions appear to have governed the types of personnel assigned to them?

IV. Concluding Comments

The Ecosystems Management Committee has concluded that the EPA could improve its current capability to protect and enhance environmental quality by adopting a more explicit ecosystems management approach. This conclusion seems to be particularly appropriate given the increasingly insistent demands that regulatory agencies produce the full range of benefits to be expected from their regulatory efforts. Increasingly, agencies must demonstrate that they respond to significant threats and that their actions produce incremental benefits that justify the incremental costs they incur. The Committee considers it unlikely that the EPA, given the nature and character of its mission, can respond adequately to these demands unless it either develops or adopts a theory or conceptual framework resembling the broadly conceived ecological systems theory we loosely defined in this Report. While we have identified a variety of research needs and priorities, we have done little more than begin what should be an ongoing process involving representatives of the scientific and technological communities.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University

and

The U.S. Environmental Protection Agency

Environmental Impact

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ENVIRONMENTAL IMPACT

I. Introduction

Accurate and comprehensive assessments of the impact of environmental perturbations are critical requirements for effective, long-range environmental planning. The Committee's recommendations of research needs to assist in the evaluation of instances of this environmental impact fall into two categories: (1) the evaluation of existing approaches and the development of innovative conceptual approaches leading to quantitative, objective, and comparable impact evaluations; and (2) the need to address specific environmental problems expected to be issues critical to the long-range management of environmental quality.

The Committee on Environmental Impact has lettered the major headings under these two principal entries A through J and A through O, respectively. The actual recommendations appear under these lettered headings but have been numbered sequentially throughout the Report 1 through 26.

II. Recommendations Associated with Conceptual Approaches

A. Regional Energy Analysis of Environmental Alternatives

(1) The overall consequences of alternative methods of environmental management must be assessed on quantitative, comparable, and objective bases. The common denominator of energy flow quantifies the major parts of both man-made and natural regional systems. Methods of analyzing regional energy flow have been recently developed and appear to be applicable to a broad range of environmental assessments (Odum, et al., 1977; Jansson & Zucchetto, 1978; Guilliland, 1978). These methods show promise in providing a basis for directly comparing interacting factors of urban, economic, agricultural, and ecosystem activity. But a holistic outlook implies the need for further research and development into the objective, scientific basis of these methods

and the application of energy budget analysis to environmental impact.

B. The Accuracy of Impact Assessment Techniques Used on Past Environmental Impact Statements (EIS's) (Follow-Up Studies)

(2) The EPA should evaluate the reliability of EIS's with the various impact assessment methodologies now available. The Agency is, after all, required by section 309 of the Clean Air Act to review those EIS's prepared by other federal agencies that address impact within the EPA's jurisdiction and expertise. It also requires applicants to prepare EIS's for construction grants and for new source wastewater discharge permit programs.

A sufficient number of EIS's have been completed in the eight-year history of the EPA to begin evaluating the validity of these impact predictions. Commonly used techniques could be evaluated on a prediction-versus-result basis. Information on the reliability and accuracy of the methodologies used in the EIS's would help the Agency's staff evaluate the adequacy of the EIS's they require. This research would also result in better environmental decision making. The research suggested here would include the following specific tasks:

(a) sorting the EIS's on completed projects with the evaluation methodology used in the prediction of impact;

(b) selecting case studies for each commonly used assessment methodology--ad hoc, matrices, checklists, networks, overlays, and models. (Note: Each major area may include sub-topics, for example, the Leopold Matrix, or highway projects done with the Leopold Matrix, or dam projects done with the Leopold Matrix, etc.);

(c) project site visits selected for each methodology and an accompanying evaluation of the actual impact to date the project has had;

(d) a comparison of EIS predictions with the actual results in each methodology class;

(e) the development of a rating system to produce (for example) a table of comparison of accuracy of each assessment class;

(f) the preparation and submission of an evaluation of the effectiveness of each methodology class examined in predicting the impact of the various types of projects examined;

(g) recommendations of refinements in the methodologies examined to improve their impact predicting ability; and

(h) recommendations of the assessment methodologies that do the best jobs predicting the impact of each project type examined, both on a cost-effectiveness basis and on an impact-prediction-effectiveness basis.

C. Environmental Impact Assessment Methodology Development

(3) This research would evaluate the tools used by the EPA in its EIS preparation activities and would subsequently help the Agency develop better tools for the EIS program. The major tasks inherent in this research follow:

(a) Induced growth forecasting for 201 Construction Grants projects. Induced growth attributable to the construction of wastewater facilities is one of the major environmental impacts of EPA's 201 funding program. This growth is difficult to forecast because of the complexity of factors that affect land use. This task would review the techniques for forecasting induced growth currently used by the Agency and would develop better techniques for the 201 EIS program.

(b) Analysis of alternatives for new source wastewater discharges. When the EPA issues an NPDES permit for a new industrial source of wastewater, the EIS should note alternatives to the action, including process and site alternatives that might reduce the facility's adverse environmental impact. The information developed by a particular industrial applicant during its site and process selection is useful, but factors other than environmental quality generally play a dominant role in an industry's screening process. This task would develop a methodology for the systematic analysis of alternative sites and processes for proposed industrial facilities. In addition to addressing environmental impact, the methodology developed would have to assess the suitability of the alternatives to meet the industry's requirements for raw materials, transportation, workforce, infrastructure, and marketing.

The EPA is required by Section 511(c)(1) of the Clean Water Act to apply the National Environmental Protection Act to the 201 Construction Grants Program and to the Agency, itself, when permitting new source industrial discharges. The methodologies developed by this research would substantially improve the Agency's ability to assess the environmental impact of these activities.

D. Verification of Environmental Impact Assessment Methodologies

(4) The EPA has a need to evaluate, sensitively and precisely, the available methodologies for assessing environmental impact. The National

Environmental Protection Act has produced hundreds of methodologies to quantify the environmental impact of a project, to aggregate all the environmental effects of a project, and to aggregate all the environmental consequences of its actions and alternatives. Thus, the EPA should ascertain the most replicable, efficient, and cost-effective methods for various project types.

The EPA has the responsibility under section 309 of the Clean Air Act to review the EIS's prepared by other federal agencies that address impact within the EPA's jurisdiction and expertise. The Clean Air Act also requires the Agency to prepare EIS's for its construction grant and new source wastewater discharge permit programs. A set of "approved" or verified methodologies, like the EPA's certified water quality tests, would produce more uniform EIS's, which could then be developed and reviewed in less time than they are under the current system. Completing this research implies the following four tasks:

(a) The replicability of methodologies and sensitivity to analyst bias could be established by creating interdisciplinary teams to assess the impact of projects currently undergoing EIS review. The same methodology would be used by each team and the results compared. Several project-methodology cases would be needed.

(b) The evaluation of objectivity (and conversely, of the tendency for personal bias or subjectivity to enter into an analysis) would lead to recommendations for altering techniques and the appropriateness of selection procedures for teams to use during their examinations of various project types.

(c) The precision of the methodologies would be assessed by using several methodologies to evaluate the impact of a given project. The results of each impact prediction would be compared. (The task would, of course, include examinations of several methodology-project cases.)

(d) The teams could assess the precision and applicability of various methodologies to project types by comparing the results of each case. The applicability of various methodologies to project types having been established, recommendations for improvement of the methodologies (that is, making them more sensitive to such project differences as location) could then be made.

E. Total Ecosystem Analysis and Environmental Impact

(5) Region-wide environmental quality depends on the specific functioning of component ecosystems. Thus, changes in the functioning of dominant and sensitive ecosystems are critical in regional considerations of environmental impact. Whereas we now have a substitute data base on organismic responses to pollution, responses should be focused on identifying and monitoring holistic parameters, which usually indicate total ecosystem functioning, especially with respect to environmental changes. Such parameters include: total ecosystem energy flow, which is an important factor in regional energy analysis (Kemp, et al., 1977; McKellar, 1978) and biogeochemical cycling and budgets of essential elements and the critical pollutants (O'Neill, et al., 1977; Guilliland, 1975).

Specific approaches to ecosystems analysis with respect to environmental assessment should include: (a) comparative ecosystem studies; (b) applied microcosm experiments; and (c) whole ecosystem modeling and simulation.

(a) Comparative Ecosystems Analysis

(6) Comparing the energy flows and chemical budgets of similar ecosystems according to such factors as human population and energy density, land use patterns, pollutant combinations, and physical alterations (channelization, bulk-heading, dredge and fill, water diversion, etc.) would (a) contribute valuable information to regional predictions, and (b) enhance the planning of development patterns and the marshaling of support from component ecosystems.

(b) Applied Microcosm Experiments

(7) The assessing and modeling of complete ecosystem activity in light of perturbations would be greatly enhanced by research into the development and experimental use of medium-scale microcosms. This research should be

aimed at solving the problems of scale and the replicability of micro-ecosystems to improve their applicability to environmental impact assessment and prediction. Once these problems were solved, the total functioning (energy flow and biogeochemical cycling) of the micro-ecosystems could be assessed directly with respect to controlled and quantified perturbations. Recent work by Pilson (1978) and Kitchen (in press) has provided a framework for this approach.

(c) Whole Ecosystem Modeling and Simulation

(8) Continued development of and experiments with mathematical simulation models of whole ecosystems should be concurrent with the theme of ecosystem analysis. These scientifically based formulations and use of simulation models provide the stage for emergence of new general principles in predicting environmental impact.

F. The Development of Guides for Assessing the Applicability of Mathematical Models for Environmental Impact Assessment

Mathematical modeling is frequently used in environmental impact assessments to predict the effects of discharges into the environment. Because of the complexity of environmental systems, these models are necessarily simplified representations of the dynamics. Simplification implies that the model makes some assumptions about the system and omits certain parameters and linkages because they are relatively unimportant to the functioning of the particular system being studied. Also, the range of conditions a model can accurately represent may frequently be limited. When models developed for one study are subsequently applied to other projects, which is frequently done in impact assessment, the results will be erroneous if the model assumptions are violated, if the relative importance of parameters and linkages differs from the model development project, or if the project conditions are outside the range of the model's applicability.

(9) Thus, we need to review all documentation for air, water, and noise models commonly used in environmental impact assessment and to prepare a guidance document that will assist the EPA's EIS staff in the determination of whether a particular model is appropriate for the project under assessment.

Section 309 of the Clean Air Act requires the EPA to review the EIS's prepared by other federal agencies that address impact within the EPA's jurisdiction and expertise. Because the EPA reviews about a thousand EIS's annually, the Agency cannot conduct extensive research on model validity and applicability whenever one is used, even though these factors can be critical in the review of a project's environmental impact. A document that describes the capabilities and limitations of the commonly used models would save resources spent in each of the ten EPA regions on documentation research, and it would promote a more thorough review of the impact of federal action.

G. Accessibility to Environmental Data

(10) The EPA should make the existing data on environmental conditions and impact more readily available to the EIS program staff members in EPA. The EPA is required by Section 309 of the Clean Air Act to review EIS's prepared by other federal agencies that address impact within the EPA's jurisdiction and expertise. The Agency must also prepare EIS's for its construction grant and new source wastewater discharge permit programs. The efficient retrieval and use of the information already available and the commensurate reduction in duplication of effort would increase the information available for EIS preparation and review and reduce the costs to the EPA and its contractors. The quality of the EIS's should also improve and less time will be required to assemble the necessary baseline and impact information. Thus, the net time between initiation and completion of the EIS's should shorten. Completing this activity would, however, require the following tasks:

(a) Since large volumes of information on the environment are available in various locations around the country, the EPA should ascertain the number, content, retrieval costs, and accessibility of each system.

(b) The usefulness of these systems' contents to EPA's EIS program must be examined; an analysis of the utility of the information made; an analysis of the quality and completeness of the data banks made; the ease and availability of access to the systems determined; the cost of the system versus the independent development of the information ascertained; and the adaptability of the data collection and selection process determined. (Can the developers present the data in a format the EPA can use? Can they alter their collection techniques to increase the utility of the information? Can new variables be added to their collection process and at what cost? How can information gaps be handled?)

(c) The staff resources and computer services available to the EPA's EIS program must be studied with an eye to producing a strategy for ensuring the EPA's efficient access to these systems.

H. The Use of Remote Sensing in Environmental Inventory Baseline Data Collection

(11) Research should be conducted into the use of remote sensing in environmental inventory and baseline data collection. The scale and number of a variety of pollution sources could also be readily inventoried with remote sensing information. This project would establish site and regional baseline information for the preparation and review of EIS's, particularly for programmatic or policy statements that work primarily on a regional scale.

More of these programmatic EIS's are written each year. They are normally referenced heavily in site- and project-specific EIS's during the actual implementation of the program. The EPA has the responsibility, under Section 309 of the Clean Air Act, to review the EIS's prepared by other agencies that address impact within the EPA's jurisdiction or expertise. The Agency must also prepare EIS's for its contract grant and new source wastewater discharge permit programs.

Access to information of this type would help the EPA prepare and evaluate these EIS's. The Agency would also be able to review EIS's more rapidly. And the system would be useful in the initial evaluation of potential sites of a variety of project types, either in EIS review or preparation efforts.

III. Recommendations Associated with Specific Problems

A. Acid Rain: A Survey of the Problem in Freshwater Ecosystems

(12) We have not yet determined the full extent of the acid rain problem as it affects fresh waters of the United States. Areas with sensitive soil and waters should be surveyed to identify the frequency and duration of natural- or anthropenic-caused low pH. Broad areas of Scandinavia, Eastern U.S., and Canada are now affected adversely by acid rain. Other areas, like the Northwest, are sensitive because of the low buffering capacity of their water and soil. But the extent of the problem (if indeed a problem exists) is not known. The extent of the problem in the Eastern U.S. is incompletely known. In view of the increased pressure we must place on the use of fossil fuels, the acid rain "problem" may well increase. Thus, the EPA must define present conditions in order to evaluate the future impact of acid rain. Placing power plants beyond the influence of prevailing winds and out of sensitive areas may become principal control measures--or certainly safety precautions. Techniques are needed, utilizing data on soil and water types, and input of sulfate and hydrogen ions from SO_2 emissions, to predict changes in water pH, metal concentrations, and resulting effects on aquatic productivity (see Wright, et al., 1976 and Likens, 1976).

B. Effect of Acid Precipitation on Energy Flow of Forest Ecosystems

(13) The EPA should support research into the effects of acid precipitation on the energy flow of the various forest ecosystems. Disruption in the energy flow pattern and rate could lead to breakdowns or reductions in the numerous benefits provided by our forests. Microcosms offer probably the best research tool for this work, at least initially. The primary benefit

of this work would be the quantification of the loss of forest ecosystem benefits attributable to acid precipitation. This information could help us assess the costs and benefits involved in pollution control regulations and individual source control programs.

This information could also help us evaluate the impact of projects or alternative project sites in the preparation and review of EIS's. And it could help in the preparation and justification of environmental legislation, regulations, and site-specific requirements.

C. Urban Runoff: The Critical Limits of Peak Flow

(14) We should determine the critical limit for increased peak flows in streams draining developed and developing watersheds and what the effective control measures are. The physical effect of water discharges following storms may constitute the principal damage to streams in urbanized areas. Maximum flows (or the ratio of maximum daily to mean daily flow) increase in proportion to the fractional precipitation coverage of watersheds with impervious surfaces. Increases above natural flows have been shown to shift bottom substrata to an extent that destroys incubating fish eggs (salmonids) and intragravel invertebrates. While our water quality standards apply to pollutant levels in storm water, comparable standards for flow increases and stream bed damage have not been seriously considered. Established limits for flow increases, and concomitant physical damage, could help guide the development of watersheds for residential or commercial use. At present, flooding and resulting property damage is (with water quality standards) the only recognized limit. Limits in peak flow increases above the natural level need to be added to water quality standards.

D. Eutrophication: Nutrients in Flowing Waters

(15) We must determine the critical limit for nutrient concentrations in flowing water. Critical concentrations as standards for the trophic

state of lakes are generally accepted. The algae mass and water clarity that nutrients cause are, on the average, reasonably predictable for management purposes. Although some lakes, and particularly reservoirs, do not conform to the predictions and need further study, the situation in our streams is much worse. Nuisance filamentous algae flourish in streams as a result of inorganic nutrient enrichment, but the complicating factor of velocity largely invalidates the application of lake critical concentrations to streams. The critical concentration of limiting nutrients for nuisance algal mass must be determined over a range of velocity before the standard can be applied to streams. Practically no research has been done with this objective, although some exists on velocity effects on nutrient uptake (Lock & John, 1979).

E. Eutrophication: Submerged Macrophytes

(16) We should ascertain the role of submerged macrophytic plants in cycling nutrients in lakes and wetlands and their desirable and undesirable densities in lakes. Until the last few years researchers have paid little attention to macrophytes and their role in either removing or adding nutrients in lakes and wetlands. Macrophytes tend to remove sediment phosphorus, rather than phosphorus from the water. This tendency has lead to their being treated as a significant internal source of nutrients in the pelagic zone in shallow lakes. But this role needs to be explored further from the standpoint of (a) the potential of macrophytes to deplete the sediment phosphorus pool once the external supply of phosphorus has decreased and (b) the time that depletion requires. Also, we must determine the extent to which macrophytes short-circuit phosphorus removed from sediment and placed back into the sediment. Furthermore, we need to know at what densities (fractional area covered) macrophytes benefit lakes in terms of food production and cover for animals, and at what level they hinder recreation. This

information could help us adequately to manage lake systems for nutrient and macrophyte control and wetlands for water and nutrient interception (see Carpenter & Adams, 1978).

F. Tolerance Limits for Suspended Sediment to Protect Stream Fisheries

(17) Our present standards for suspended sediment are based on turbidity (nephelometric) measurements, and these standards are rather arbitrary. The damage from suspended sediment is largely an effect of the mass and particle size of sediment that settles on the stream bottom, blocks intragravel water flow, and smothers invertebrate habitat. Limits in terms of concentration (mass per volume) should be defined for different stream types. Considerable research exists on the effects of suspended sediment in streams. General limits might possibly be defined through a review of existing literature without much additional experimental research. The state of this problem can be illustrated by the one page devoted to it in the "Blue Book" (Water Quality Criteria, 1973), which includes no citation of the pertinent, existing literature on the subject.

G. The Relation Between Phosphorus Loading in Lakes and in the Depletion of Oxygen With Reference to the Production of Desirable Fish Species

(18) Most eutrophication research has been directed to establishing controls to benefit recreation and water supplies--algae and water clarity (Vollenweider, 1976; Dillon & Rigler, 1974; Chapra, 1977). The limits that would protect sensitive fisheries are uncertain and are thought by many to be much higher than the limits for recreation (Oglesby, 1977). To manage lakes and reservoirs effectively, therefore, we must determine the limits for fisheries. Conflicts in the Clean Lakes Program between the fishery and recreation interests have been difficult to resolve.

More specifically, research should be directed toward defining an optimum P loading in lakes of different morphometry to balance the benefits of increased production (fish food) against the detriments of a decreased oxygen content. At what point in P loading do oxygen decreases at the sediment-water interface begin to limit fish growth or reproduction? What are the critical life stages for the more sensitive lake species? Are the often observed tendency in plankton to become colonial and the presence of filamentous, the sometimes-toxic blue-green algae, and the smaller zooplankton undesirable for the growth of sensitive fish species? When a large biomass of blue-green algae accumulates, it represents nutrients not being utilized by higher levels. That condition probably represents over-production of photosynthate from the standpoint of fish. Coupled with the limitation to growth and reproduction and sometimes death from low oxygen, this condition indicates that a reduced P loading should be more optimal for the production of sensitive fish species. In stratified lakes of moderate depth we find some indication that a critical P load for recreational purposes should not differ greatly from that for fish (Welch & Perkins, in press). But others argue that the limit for fish is much higher.

H. The Definition of the Physical Factors Quantitatively That May Limit the Dominance of Blue-Green Algae in Eutrophic Systems

(19) Blue-green algae dominates many eutrophic systems when nutrient (P) loading increases; however, they do not dominate many turbulent, moderately flushed eutrophic systems. The cause of this phenomenon could be the dilution of allelopathic substances secreted by blue-greens that discourage the growth of competing species, the renewal of the soluble portions of nutrients favorable to competitors, or the nullification of the competitive advantage blue-greens have for the light when they float in non-turbulent situations. Experiments in artificial and natural systems should be encouraged with the goal of developing control measures for nuisance blue-green populations other than reducing nutrients (Shapiro, et al., 1975).

I. The Predator-Prey Effects on Blue-Green Algal Blooms

(20) Can nuisance blooms of algae, particularly blue-greens, be recycled into the food web as fish flesh by manipulating components of the grazing food chain? In lakes where nutrient controls are impossible, the blooms can possibly be reduced in magnitude and frequency by reducing the planktivorous fish (those fish that eat large zooplankton) by adding predatory fish (those fish that eat the plantivorous fish). This approach has been proposed and verified to some extent in microcosms, but it needs to be tested on a large scale. If it proves to be valid, this approach could provide a useful tool in the Clean Lakes Program (Shapiro, et al., 1975).

J. Limits for Suspended Sediment and Toxicants

(21) Should the recommended limits for suspended sediments and toxicants be expressed as a maximum concentration (as it usually is now)? or an average concentration over some designated exposure period? or a maximum concentration with some frequency of occurrence? Both lethal and sublethal effects often depend on duration and concentration level. But, while recommendations exist for maximum permissible concentrations of many toxicants under long-term exposure, we find no guidance in applying these limits to natural waters. If the maximum concentration in a stream were controlled to a level less than the long-term permissible concentration, it would tend to be supraconservative. On the other hand, if the average stream concentration were used, and controlled to within the long-term limit, lethal maxima might actually exist for periods sufficient to cause direct mortality.

While limiting the maximum concentration at any time might be a safe approach for protection (supraconservative), its usefulness diminishes when one wants to project improvements (benefits) from reducing instream concentrations and waste loads. Clearly, we need an acceptable formula, possibly based on the existing literature, to express tolerable limits for fish that take into consideration the concentration and exposure periods.

K. The Effects of Toxic or Hazardous Materials Spills

(22) Accidents involving the transportation of toxic or hazardous materials have occurred in the past and are bound to occur again. Most notable among some of these accidents are the breakup of oil tankers and railroad and highway wrecks. The short-term and local effects of these accidents are often dramatic. But what are the long-term effects? How has the environment recovered from these accidents? What changes have occurred in the plant and animal life in the areas surrounding such accidents? How extensive have the effects been?

L. The Effects of Slurry Pipeline Transportation

(23) Transport by pipeline is a most favorable method for many products. But when the product carries a carrying agent, the availability and disposition of the carrying agent may present problems at either the source or destination. We must ascertain the systemwide environmental effects of slurry pipeline operation for a variety of products and carrying agents before we commit major investments to this transportation mode.

M. Alternatives to the Use of Salt for De-Icing Winter Roads

(24) The use of salt, a relatively cheap de-icing agent, on the nation's highways melts the snow and ice efficiently, but also corrodes the vehicles and the pavement and enters the ground water system and adjacent streams. If the long-term effects of this road salt are more severe than we can accept, we must find suitable alternates and determine the effects these alternates have.

N. Impact of the Use of Alternate Fuels in Transportation

(25) The dwindling supply and the limited availability of domestically produced petroleum-based fuels portends serious disruptions in our

transportation system, even if effective energy conservation measures are implemented. The use of alternate fuels to power the various transportation modes is one strategy to minimize any adverse impact on the environment that might accompany significant changes in the transportation system. Three such alternate fuels include liquid hydrogen, gas from coal, and gasahol.

The production, transportation, storage, handling, and utilization of these alternate fuels will, themselves, have impact on the economic, social, and natural environments. We should understand these effects before making major policy and production decisions on the use of these and other alternative fuels. We should undertake pilot programs to determine as many of these effects as possible, under conditions that permit the modification or cessation of a program should it become apparent that the negative effects will outweigh any positive effects.

O. The Effects of Converting a Large Percentage of Highway Passenger Vehicles to Either Diesel or Electric Power

(26) Much research has been conducted on the pollution produced from gasoline-powered engines. Commensurate work does not seem to have been done for diesel-powered engines. We need to know what the products of diesel combustion are and what their effects can be on the biosystem. What concentrations are acceptable? What concentrations would result from a major shift to diesel-powered engines? What effect would this shift have on the availability of fuel?

With regard to the possibility of electrically-powered vehicles, we must determine the effect on the entire system of such a major shift to electric power as well as the direct effects on air quality and noise. The availability, production, handling, and disposal of the various elements of battery production and operation should also be examined more fully.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

Ecosystem Restoration

April 26 and 27, 1979

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ECOSYSTEM RESTORATION

I. Introduction

Ecological systems provide society with values that can conveniently be grouped as goods, services, esoteric preferences, and long-range self-maintenance mechanisms. Pursuant to its mission of maintaining the quality of the human environment, the Environmental Protection Agency must evince a keen interest in the restoration of disturbed or damaged ecosystems as well as in those systems which, through human activity, may become disturbed. Clearly, some of these systems must be returned to and maintained in their natural or near-natural state if we are to protect our natural heritage for future generations. Ecological refuges not only protect the basic genetic endowment, but they also provide the genetic and species resources necessary to restore damaged ecosystems wherever they may occur. Still other ecosystems must be restored to some relatively stable, but less than natural, state capable of providing society with goods and services.

Ecosystem restoration must, moreover, be carried out with a full knowledge of the structural and functional characteristics of the states to be achieved. Restoration must also be accomplished with a knowledge of the most effective and efficient technology available for the process. These technologies include the effective manipulation of the physical and chemical qualities of habitats, and the technologies of effective species stocking and restoration programs. The emerging field of ecosystem restoration and enhancement has thus become a cornerstone of our ecosystem management capability.

Those involved in this new technology must develop a detailed knowledge of the fates and effects of each type of system perturbation. We will need to know the rates of recovery and the limits of tolerance beyond which perturbed systems cannot recover to desired states. We must couple all this information with a knowledge of the reversibility of the states of the systems that have been subjected to disturbance.

To develop this new field, we must carry out research now in certain critical areas and with a focus upon specific ecosystem types. In the sections that follow, the Committee has identified and briefly discusses the dimensions of restoration and critical research needs.

II. Dimension of Restoration Processes

The damage suffered and the subsequent recovery potential of stressed ecosystems depend upon three basic sets of factors or dimensions: the type of system perturbed, nature of the disturbance, and mode of operation of the disturbance agent. We discuss each of these dimensions briefly in the paragraphs that follow.

A. Ecosystem Types

Although a variety of ecosystem types exist, for the purposes of this Report they may conveniently be grouped into the ten categories shown in the accompanying table. The compositions and processes of these ecosystem types vary in relation to climate, geographic position, and altitude.

MAJOR ECOSYSTEM TYPES

Forests
Grasslands
Deserts
Dry tundra
Lakes
Shallow wetlands (marshes, swamps, bogs, coastal wetlands, and wet tundra)
Streams and rivers
Estuaries
Continental shelves
Non-natural ecosystems (like agricultural lands and reservoirs)

For example, an estuary in Oregon may differ in species composition and certain basic functional characteristics from one in Louisiana or Massachusetts. Therefore, in studying tolerance and responses to perturbations, one must give consideration to this heterogeneity. Furthermore, one must make a conscientious attempt to understand the restoration needs of each system type in all its various manifestations.

B. The Nature of the Perturbation

The major types of ecosystem perturbations have been grouped into the nine categories listed in the accompanying table.

MAJOR TYPES OF ECOSYSTEM PERTURBATION

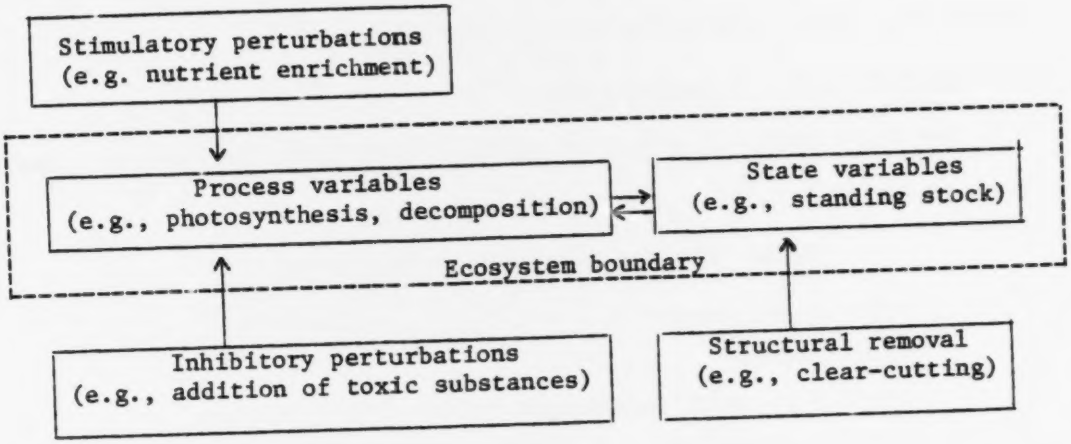
Nutrient enrichment
Acidification
Addition of toxic substances
Nutrient depletion
Surface mining
Habitat modification (like stream flow alteration)
Destruction of native species (like impingement and entrainment)
Introduction of alien species

It is important to understand how each of these perturbation types affects each ecosystem type. But the nature and severity of the effect will also depend on the intensity, duration, and seasonal occurrence of the perturbation events, and one must study these factors as well.

C. Mode of Perturbation Activity

The characteristic mode of response of an ecosystem to a given type of perturbation depends upon whether the primary effect of disturbance is upon the system's structural components or upon its functional processes. Some effects are stimulatory, others are inhibitory, and still others affect the system's structural characteristics. These effects are illustrated in the accompanying figure.

MODES OF ACTION OF PERTURBANTS ON ECOSYSTEMS


Stimulatory perturbations
(e.g. nutrient enrichment)
Process variables
(e.g., photosynthesis, decomposition)
State variables
(e.g., standing stock)
Ecosystem boundary
Inhibitory perturbations
(e.g., addition of toxic substances)
Structural removal
(e.g., clear-cutting)

Present experience suggests that ecosystem restoration is more difficult to accomplish when processes are altered than in cases in which only state variables have been primarily affected. The modes of action of the major types of ecosystem perturbation appear in the table on the following page.

III. Establishing Research Priorities

Habitat restoration has been carried out on an empirical basis for many years, but the effort to develop a sound experimental and theoretical basis for ecosystem restoration is a relatively new endeavor. Therefore, there is a great deal to be done both in establishing a firm foundation and in applying this knowledge to practical problems. Hence, we must establish research priorities that address our need for both basic and applied knowledge. Related research is already underway both within and outside the EPA, and the possibility of integrating and building upon the knowledge that develops should be given consideration. Therefore, in enumerating research priorities, the Committee has taken into account the following considerations:

(a) opportunities for obtaining important information rapidly,

(b) opportunities for building upon promising intra-agency programs already in progress,

(c) opportunities for drawing upon and cooperating with related on-going programs outside the Agency,

RELATION OF PERTURBATION TYPE WITH MODES OF ACTION

Modes of action / Perturbations	Stimulatory	Inhibitory	Structural
Nutrient enrichment	X		
Acidification		X	
Addition of toxic substances		X	
Nutrient depletion		X	
Surface mining		X	X
Habitat modification			X
Habitat destruction			X
Destruction of native species			X
Introduction of alien species			X

(d) establishing a concern for practical problem areas of current importance, and

(e) initiating programs where the information will be of great importance but in which the problem may require long-term study before reliable information becomes available.

The Committee has concluded that high priority should be given to the following areas of ecosystem restoration research:

(1) We must develop and evaluate ecosystem restoration techniques at all levels.

(2) We must initiate studies of situations in which extensive perturbation dictates an extensive restoration effort (for example, at Kaneohe Bay, Hawaii).

(3) We must develop and evaluate methods of studying large-scale restoration problems through small-scale systems.

(4) We must develop methods for coordinating ecosystem restoration studies with related on-going ecological programs to enhance information exchange and data correlation.

These are, of course, general areas of interest in ecosystem restoration research. The following two sections, "Specific Research Needs" and "Developing Restoration Strategies," suggest some specific research and make specific recommendations. These recommendations, both general and specific, are numbered sequentially, 1 through 14, in the Report.

IV. Specific Research Needs

The research areas listed below appear in order of the priority the Committee considers appropriate.

(5) We must develop methods for defining the "desired state" (natural or disturbance) of the several types of ecosystem. In order to manage for ecosystem recovery, one must have a clear definition of the state to which it should be restored.

(6) We must develop, from cost-effective and technological points of view, a science of ecosystem restoration enhancement. Such a science should include the following components: (a) the preparation of substrates (for example, mechanical preparation and fertilization); (b) the removal of perturbants (by natural or artificial means); (c) the use of waste products to aid in restoration; (d) the development of species restocking programs from refugium ecosystems; and (e) the use of specific strains of biological organisms for ecosystem restoration. The progressive development of such a science should enhance the values of ecosystems in the service of society and reduce the cost of restoration.

(7) For each ecosystem and perturbant type, we should define the steps and rates of recovery and the extent to which enhancement technology can facilitate the recovery process. Management must be able to predict the consequences of alternative recovery strategies so that it can select and implement the most appropriate means of achieving the desired system state.

(8) We should define the degree to which ecosystems can be displaced while retaining the capacity to recover once the perturbation is relaxed.

This definition should be established for different ecosystem types, modes of disturbance, and patterns of perturbation. It should also be studied both with and without human intervention in the recovery process. Decisions concerning management strategies should be based upon knowledge of response patterns and of the reversibility of ecosystem state following known types and degrees of perturbation.

(9) We must determine the desired number, types, sizes, and maintenance costs inherent in developing extensive, natural ecosystem refuges. Ecosystem restoration cannot be undertaken unless the species and genetic stocks are available to bring the system to the desired state, and the species for restocking clearly will not be available unless we take deliberate steps to ensure their survival.

(10) We should develop the techniques whereby extensive ecosystem perturbation response and recovery patterns can be studied in miniature (that is, with microcosmic systems). Since it is generally unrealistic to experiment with extensive ecosystems, we must use miniaturization to simulate ecosystem recovery dynamics following the relaxation of perturbation.

(11) We must develop techniques whereby mathematical modeling procedures are tightly coupled with ecosystem recovery studies, both experimental and natural. Extensive ecosystem management must ultimately depend upon mathematical simulation to aid in predicting the consequences of alternative management strategies. In most instances, however, the validity of predictive ecosystem models remains to be established.

V. Developing Restoration Strategies

Ecosystem restoration, as part of the field of ecosystem management, involves a series of practical problems whose solutions depend heavily upon theoretical knowledge and the judgment of experienced scientists. In the absence of basic knowledge and critical judgment there is ample latitude for ecosystem mismanagement and deterioration, which could occasion serious social consequences. Wisdom, therefore, dictates that basic and applied science be wedded from the outset in the development and application of ecosystem restoration. Thus, the Committee recommends that these three elements always be combined in this work:

(12) We must adopt a broad perspective on all applied problems. This approach would entail factoring all practical problems into those theoretical and applied elements required to achieve a satisfactory solution.

(13) We must acquire and mesh the theoretical and applied knowledge bases required to achieve the solution.

(14) We must integrate the work of theoretical and applied scientists by appropriate means so that procedures can be established and decisions made on the basis of all the appropriate considerations.

Whereas these three recommendations probably relate to most applied science situations, ecosystem restoration is an area that specifically demands the union of theoretical and applied approaches if significant progress is to be made. The development of restoration strategies calls for broad knowledge and considerable creativity.

Considering the rate of deterioration of the life support systems of this planet, ecosystem restoration must become a major endeavor of all societies, and the necessary technology is long overdue. Remediation of this situation, itself, must be considered a matter of highest priority. The guidelines presented in this Report provide a still primitive, but significant, focus on the absolutely essential balance that must be achieved between the human species and its environment.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
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Economic Solutions

May 2 and 3, 1979

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ECONOMIC SOLUTIONS

I. Introduction

With an annual expenditure of several billion dollars, the Environmental Protection Agency carries out the task of protecting the health and general well-being of over 220 million Americans from the potentially harmful repercussions of taking part both as consumers and producers in the largest and most complex agglomeration of economic activity in the world. Moreover, the Agency's concerns extend to problems that many years hence can be expected to confront our children, grandchildren, and great-grandchildren.

The reports of the 19 other Committees, each consisting of experts on their subject, examine many of the problems in analyzing the generation of pollutants that must now be controlled, and provide the Agency with guidelines for effective discharge of its responsibilities.

The effective use of this information to achieve an assessment of the environmental situation and anticipated changes to be brought about by future economic growth and new technology, necessitates the establishment of a major recording and analytical system consisting, among other elements, of a comprehensive data bank and appropriate physical and economic relationships.

The Committee considers management of airborne, waterborne, and solid waste residuals in isolation from each other as undesirable in view of the market and non-market linkages among them. These linkages include treatment alternatives (such as waterborne versus solid wastes); non-treatment alternatives (including input substitution, technological change, and recycling); changes in the timing and location of discharges; and augmentation of the environment's assimilative capacity. Present policies emphasize technologically based effluent or emission standards, yet these standards bear no inherent relationship to the pertinent natural systems in question. We need linkages with reasonably acceptable diffusion models for the atmosphere and water courses in order to translate a quantity of residual emissions at some point A to an ambient concentration at some point B.

Two additional components are required to close the model: First, we should establish a set of receptor-damage (dose-response) relationships that can be used to translate changes in ambient concentrations into effects on living things and other substances. Second, since environmental quality is a public good, its provision and evaluation raises important political problems which, to a large extent, reflect the distribution of benefits and costs. The political linkage can be accomplished through relative weights that reflect political acceptability or influence. Although we cannot always ascertain these weights, we can explore their implications. The advantage of this integrated approach lies in its ability to sketch the range of alternatives worth considering.

Any decision to increase the quantity and quality of environmental services involves both costs and benefits. The costs include foregone goods and services, typically of a tangible nature, while the economic benefits represent the values individuals place on improvements in their physical and mental environment, as well as specific health benefits. While most of these values can ultimately be measured in dollars and are thus commensurate with costs, we should realize that some of them must be assessed in other ways. Nevertheless, all of the primary relationships in question are essentially physical in nature. The task of benefit estimation, that is of obtaining data and building models, can be difficult; yet the state of the art has advanced substantially in the last 15 years (cf. Kneese & Bower, 1972, Chs. 3 and 6; Peskin & Seskin, 1975; Brookshire, et al., 1979). More extensive efforts in this area are likely to yield substantial benefits in future years as the trade-offs between market and non-market goods become even more important. The recommendations presented below serve as a basis for allocating scarce resources for research on economic solutions to environmental problems where, in the opinion of the Committee, the returns will be the greatest.

In the remainder of the report, we first present our specific recommendations and their rationale. Following the discussion of the rationale, an attempt is made to place broad priorities on the recommendations.

The following sections, lettered A through F, detail the Committee's recommendations of the specific areas in which research should be expanded. Several of these recommendations apply to areas that have often been considered outside the area of traditional economic research. Nevertheless, they are important to the development of better economic analyses. For example, the Committee believes that much greater efforts must be made to link the research on physical and health effects and the research on economic benefits. While we established no rigorous priority scheme for reaching these recommendations, we did consider Recommendations 5 and 7 to be of somewhat lower priority than the rest. The recommendations, numbered 1 through 7, appear in sequence throughout the Report.

II. Recommendations

A. An Integrating Analytical and Data System

One of the more valuable roles that economists can perform in a research organization is to provide a framework for integrating different research efforts, and linking these efforts with decision making. The idea of the conceptual integrating system was discussed in the Introduction to this Report. This system should be reflected in an integrated system of models and data bases that promotes the assemblage and analysis of data in a systematic manner.

The EPA Office of Research and Development did attempt to support the development of such a system several years ago. Called the Strategic Environmental Assessment System (SEAS), it attempted to combine all information into one huge computer model. A number of shortcomings were associated with this effort, and after several years of developmental work it was abandoned. The Committee does not propose the resurrection of SEAS, but the work done on that effort and many of the lessons learned during that period provide a useful starting point for the development of an integrated analytical system. The resulting system would probably differ from SEAS in many respects, but it could also make use of some of its appropriate components. The fact that these components already exist (and in some cases have undergone further development and improvement elsewhere), combined with the expectation that many of the functions undertaken by the integrating system ought to be accomplished whether or not such a system exists, makes this proposal quite reasonable in terms of its cost.

The first stage in developing this system would be to undertake a careful review of the existing SEAS components, the existing data systems, the previous experience with SEAS, and the analytical and data needs of the Agency in order to design the most useful system of tools and data banks possible. This review and design ought to be carried out under the supervision of a special committee of the Science Advisory Board, and in close consultation with the program offices and the regions. Although we would have to await the outcome of this effort to determine the precise structure and functions of the system, we can predict at least two major differences between it and the previous effort. The first relates to the Agency's data collection efforts, and the second relates to regional analysis.

At the present time, the EPA spends substantial amounts of money collecting data on such items as the number of firms in an industry, production levels, consumption rates, pollution emissions, their health effects, and the general state of the environment. But the data so collected and processed are not integrated and, hence, their use is limited in scope. In other words, there has been no attempt made to integrate the data, and preserve them in a way that makes them easily available for subsequent use. There is also a distressing lack of quality control and consistency in the data collection effort to date.

Some of the important functions that integrating models can provide follow:

(a) they provide a data depository designed to be used and not just to provide dead storage,

(b) they automatically provide a way to link the various data sets,

(c) they force a measure of quality control and consistency on the data collection effort, and

(d) they allow the data to be analyzed from many different perspectives.

Thus the development of an integrating model, undertaken with the specific purpose of incorporating the data presently being collected by the Agency, becomes a major tool in improving data collection, lowering data processing costs, improving data analysis, and guiding new data collection.

The system should also be designed to provide much better information at the regional and subregional levels. The earlier system was first built at the national level, in which attempts were made to allocate shares of the national totals to the individual regions. This approach was not successful. In order to be useful at the regional level, the system has to be built upon region-specific information--for instance on the number of establishments, the characteristics of the region and its population, etc. This new effort should provide valuable insight into the Agency's overall management and planning of its research and data collection activities, the process of planning such a system, and the establishment of linkages throughout the system. Additional benefits should appear as soon as personnel begin the process of assembling the required information and generating the appropriate data. This process will begin to create the necessary linkages between various units within the Agency that would allow them a better perception of how their individual efforts fit into the systems.

(1) Thus, the Committee sees the need for the conceptual planning of an integrating analytical system to incorporate a variety of data bases and analytical models, and it recommends that the EPA pursue the development of such a system.

B. Methodological Development: Human Health

The development of a detailed methodology for measuring health status in terms of individual function that facilitates the detection of limited encroachments on health stemming from environmental factors is an obvious research need. This research would involve the definition of individual function in terms of social, psychological, and physical aspects; the development of specific measures for each aspect; and the validation of these measures.

The functional measures of health status would subsequently be used to measure adverse low levels of decrements in health status that are not normally detected with currently available methodologies and that tend to have significant social and psychological effects. That is, the current state of the art in health status measurement (in terms of mortality, morbidity, and disability) cannot assess low levels of toxicity, noxicity, and other environmental hazards to human function.

(2) Thus, the Committee sees the need to improve the EPA's ability to determine the economic benefits of its pollution control activities by developing a detailed methodology for defining and measuring health status sufficiently sensitive to low levels of encroachment on individual functioning and relevant to behavioral analysis.

C. Health Production

We must begin to investigate the relative contributions environmental factors make to the sustenance of health in a given population, taking into account individual or group differences in life style, genetic makeup, economic status, demographic factors, and health care costs.

This investigation should include the following components:

(a) an examination of the relative effects of specific environmental contaminants on the health status of the population, with the latter assessed at a high level of specification in terms of individual functioning or behavioral performance;

(b) an empirical assessment of the relative risk or vulnerability of specific sub-groups (by age, sex, morbidity experience, medical family history, and other relevant variables) in the population in terms of adverse health attributable to environmental contaminants; and

(c) an interregional comparison utilizing existing sets of data and the collection of new data appropriate for purposes of this investigation.

We need this research because much of the information we have to date on this subject is not sufficiently precise to permit assessments of environmental effects on special levels of health status in the population.

(3) Thus, the Committee sees the need to improve the EPA's ability to determine the economic benefits of its pollution control activities by investigating the relative effects of environmental factors on health status while controlling for differences in life styles, genetic makeup, economic status, demographic factors, and the availability of health services.

D. Uses of the Natural Environment

We need additional research on the various ways people use the natural environment other than for the production of physical goods and life sustenance. Such research would indicate those components of the biosphere that are directly or indirectly used by people to obtain satisfaction. This research must address such uses as recreation, the observation of vistas or species, and the satisfaction obtained from the knowledge that ecosystems endure with minimal human intrusion. The information obtained by these research efforts would be vital to a proper determination of the value people place on reducing or avoiding specific changes in the natural environment and would provide a starting point for research into the questions of valuation.

(4) Thus, the Committee sees the need to improve the EPA's ability to determine the economic benefits of its pollution control activities by analyzing people's use of the natural environment as a function of the quality of the environment.

E. Avoidance Activities

We should conduct studies to identify the methods by which people avoid undesirable conditions in the environment. Many possibilities exist for avoiding pollution or its consequences. These include moving one's residence or place of work, installing air conditioners or heaters to change the temperature or other aspects of the air, the use of noise reduction or masking devices, and many others. Determination of the methods of choice and their frequency of use would provide valuable indicators of the environmental conditions people object to and would also serve as a starting point for determining the value people place on different states of environmental quality.

(5) Thus, the Committee sees the need to improve the EPA's ability to determine the economic benefits of its pollution control activities by analyzing avoidance activities and other behaviors intended to offset negative environmental effects.

F. Economic Valuation

In those cases where the economic benefits of pollution control are most easily and accurately measured by first determining the effects of physical damage, we should certainly place an economic value on such damage. The best known problem area here is the valuation of mortality (or longevity). Recent approaches to this problem have included analyses of the value society places on riskier occupations. These analyses suggest that additional research in this area could lead to much greater public acceptance of such valuation methods. In general, where the benefits are most easily and accurately obtained by direct valuation techniques without determining the effects of physical damage, the methodologies are more primitive and have been subjected to more criticism. Nevertheless, we are likely to realize substantial returns from further methodological research and experimentation. For example, although the combined property value and willingness-to-pay survey used by the University of Wyoming study of Los Angeles (Brookshire, et al., 1979) appears to hold some promise, it should be replicated so that the methodology can be refined and verified.

Since the EPA ultimately finds the net dollar benefits of pollution control activities useful either as benefit-cost information to make decisions or to justify its activities economically after making a decision, the goal of this research should be to improve the EPA's ability to quantify the benefits of its activities as rapidly as possible to meet the increasing demand for such information outside the EPA (see Andrews & Waits, 1978, especially Chapter 4). The present level of natural and external resources devoted to improving the EPA's ability to present such estimates is too low to meet the outside pressure for reliable estimates. This inadequacy is liable to cost the EPA dearly in the next few years as Congress becomes increasingly concerned with the economic costs of EPA programs.

(6) Thus, the Committee sees the need to improve the EPA's ability to determine the economic benefits of its pollution control activities by analyzing the economic valuation placed on physical decrements in the environment in relation to other values and opportunities.

G. Management

Broadly conceived, four approaches are available for the management of environmental problems:

(a) attempts to regulate and prohibit discharges;

(b) attempts to provide abatement incentives in the form of charges, fees, subsidies, or marketable permits;

(c) attempts to encourage voluntary compliance through provision of better information in the form of labeling and similar activities; and

(d) direct public provision of certain services such as recreation. (While not ignoring the other alternatives, the Committee emphasizes additional research on alternatives b and c.)

Changes in the economic incentives structure must play a larger role in successful environmental management. There is evidence that emissions charges, if properly implemented, have advantages in efficiency, equity, and cost-effectiveness compared to direct regulations and subsidies. A charge system requires fewer enforcement tools because it changes the incentive structure facing the polluter; delay no longer pays. Even if he wished to delay, a polluter is no longer in position to argue with a regulatory agency over the technical and economic feasibility of its abatement options since they are now irrelevant. The polluter's main concern is to choose the most economically efficient abatement alternative. Since it will continue to pay a charge for whatever it continues to discharge, the firm will have an incentive to search for improved abatement techniques to reduce its charge payments in the future.

For example, a charge-based auto emission control program would provide manufacturers and owners with continuing incentives to produce and drive cleaner cars, and it would reward those who do and penalize those who do not. A system of charges would avoid the arbitrary and stringent standards and deadlines that compel manufacturers to adopt short-run strategies and avoid innovative methods. The current program attempts to decide in Washington exactly what may be discharged each year and exactly what investment and production technologies are acceptable. An incentive-based program would provide continuing inducements to reduce pollution and adopt innovative technologies.

Finally, individuals must frequently adjust to changes in environmental pollution levels in a voluntary manner. (Indeed, in some circumstances this may be the least costly way to "abate" pollution.) The efficiency with which individuals avoid pollution damages depends in part on the quantity and quality of information available on the effects of pollution and its control. Additional research on the effects of labeling, advertising, and individual behavior should be considered. This research includes analysis of existing information programs as well as newly-developed demonstration projects and grants in this area.

(7) The Committee recommends an analysis of the effectiveness and efficiency of alternative means of governmental intervention in the area of pollution control, with particular emphasis on the role of individual incentives and rewards.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
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Exposure of Human Populations and the Environment

April 16 and 17, 1979

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EXPOSURE OF HUMAN POPULATIONS AND THE ENVIRONMENT

I. Introduction

Clearly, those who formulate and implement environmental regulations must focus on improving their estimates of the pollutants in the environment to which human populations are exposed. Only by focusing on exposure can one begin to derive dosage-response curves for those populations that have experienced health effects attributable to the environmental pollutants. This Committee undertook to isolate the principal research needs related to improving the estimates of population exposures. In doing so, the Committee attempted to correlate its recommendations with the legislative mandates of the Environmental Protection Agency (EPA).

The recommendations that follow do not necessarily include all the promising areas of research and development appropriate to the EPA. Rather, they represent the shared perceptions and understandings of the Committee members. The recommendations were, however, thoroughly discussed and do represent a consensus.

II. The Recommendations

The Committee has presented its recommendations by media categorization because this format lends itself to ongoing EPA organization for research. Where recommendations are multi-media in application, it has been noted.

A. Air

(1) The exposure of individuals to the seven Air Quality Criteria Pollutants should be determined with personal dosimetry if possible. Where personal dosimeters are not available, they should be developed. Individuals of different sexes, ages, activity patterns, residences, and occupations should be studied. These investigations should be performed in conjunction with modeling efforts to provide predictive bases for estimating population

exposures.

(2) Exposures to air carcinogens among populations in the vicinity of stationary sources should be determined for the purpose of correlating these exposures with cancer incidence investigations.

(3) Source characterizations for non-criteria pollutants should be improved to facilitate population exposure estimates.

(4) Emphasis should be placed on characterizing and measuring personal exposures in such special environments as homes, offices, schools, and hospitals.

(5) The EPA should review the rationale for establishing definitions of two functions of suspended particulate matter, respirable and non-respirable, for a National Air Sampling Network. Specifically, we ought to know whether the current EPA definitions related to exposures can be reliably correlated with health effects and whether they are consistent with the characterizations of inhaled particulates for risk estimation by such other professional groups as the American Conference of Governmental Industrial Hygenists and the International Congress of Radiological Protection.

(6) The sampling and analytical ambiguities related to the dosimetry of air pollutants should be resolved where they are known to occur. Specific cases include the nitrate formation in ambient air sampling and the vapor phase alterations related to auto exhaust exposures.

B. Pesticides

(7) Groups of individuals occupationally exposed to pesticides, like farm workers, mixer-loaders, applicators, and retail-wholesale distributors, should be examined to measure exposure incidences against any possible chronic effects from multiple exposures.

(8) The techniques for determining the residues of pesticides, then metabolites and degradation products in human tissue, excreta, and

environmental media should be improved.

(9) A broad-based epidemiological program designed to assess the health effects of significant levels of pesticide residues on previously exposed populations should be developed. The emphasis should be placed on correlating exposure with incidences of chronic disease.

C. Noise

(10) High-risk groups, including children and young adults, should be studied to determine the effects exposure to high-level noise has on these persons. In particular, the effects of noise from toys, rock music, and other sources at home or during leisure activities should be studied.

(11) The reliability of sound-level meters and noise dosimeters should be investigated to determine the extent of readout differences that may result when they adhere to the American National Standard Institute (ANSI) Type 2 Specifications adopted by the present rules and regulations. In particular, the tolerances allowed by the Type 2 Specifications should be reconciled with the form of allowed daily tolerances set forth in the Occupational Safety and Health Administration exposure limits. In addition, the differences that may result in Type 2 sound-level meter readouts permitted at frequencies above 10,000 Hz should be investigated and placed in perspective vis-a-vis exposures.

(12) Hearing tests more sensitive and reliable than conventional threshold tests should be developed so that examiners can detect noise-induced hearing changes as quickly as possible. An additional objective might be a susceptibility test to identify those individuals particularly susceptible to noise-induced hearing problems.

(13) The effects of simultaneous exposures to steady state and impulsive noises should be studied to provide a basis for setting noise exposure tolerance limits.

D. Non-Ionizing Radiation

(14) The current EPA ionizing radiation program should be maintained, but not expanded. In general, our understanding of the effects of ionizing radiation is much more complete than that of the other agents. The Committee feels, therefore, that efforts should focus on elevating our knowledge of the other agents to the level of understanding we have achieved in the area of ionizing radiation.

(15) Techniques and guidelines for measuring frequencies, modulations, and power levels of radiation of sub-infrared wavelengths should be developed.

(16) Dosimetry studies should focus on exposure to non-ionizing radiation (of wavelengths lower than infrared) in different functional environments like work and the home. Power intensity-frequency profiles should be obtained for populations that receive high doses of particular types of non-ionizing radiation, like electric utility linemen, radar operators, and persons who frequent high-power transmission or communication centers.

(17) The EPA should consolidate its communication channels with other federal agencies (Department of Energy, Department of Defense, the National Bureau of Standards, and the Electrical Power Research Institute) also involved in determining the biological effects of non-ionizing radiation.

E. Water (Microbiological Issues)

(18) The infectious and potentially infectious agents that may be discharged from suspected pollution sources, including wastewater treatment plants, should be isolated. For example, the techniques of waste disposal on land (including irrigation methods) should be studied, as should waste discharges treated with activated carbon.

(19) The possible alternate disinfecting methods and substitutions for chlorine in non-disinfecting water and wastewater usage should be examined.

In addition, suitable indicators (test organisms) that provide reliable disinfection efficiency must be found. (Note: The Committee considers coliform organisms unsuitable.)

(20) The EPA should undertake or underwrite thorough studies to determine the chemical contaminants of drinking water, with particular emphasis on synthetic organic chemicals.

(21) The EPA should also concentrate on studies of human exposure to carcinogens and cardiovascular agents in both surface and ground water supplies. These studies should include measurements prior to treatment, immediately following treatment, and at the consumers' taps.

F. Hazardous Waste Disposal

(22) The EPA should develop a strategy for monitoring human exposure to toxic chemicals from existing chemical waste sites. Investigations that delineate ground water movements and capacities; soil types and their respective capacities to retain chemicals; and the influence of rainfall, among other factors, would be most useful. This Committee hesitated to make more specific recommendations in this area, but we agreed to transmit our sense of urgency regarding the need for much more understanding than we have now of the interaction between toxic wastes and the environment, the control options, and the methods of monitoring human exposure. This research would also provide a strategy for treating chemical wastes in the future.

G. Analytical Need

(23) The EPA should continue to improve its techniques for collecting, identifying, and quantifying pollutants in all media--for example, the specification of inorganic elements in water; the specification of non-purgable, non-volatile organic chemicals in water; and the collection media for organic chemicals in air and water.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

Measurement and Analysis: Biological Monitoring

April 17 and 18, 1979

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MEASUREMENT AND ANALYSIS: BIOLOGICAL MONITORING

I. Introduction

The Committee began with a charge to identify research needs, to recommend priorities in the area of biological monitoring, and to provide justification for these needs and recommendations. Thus, the Committee developed an outline summary of biological monitoring concepts to serve as a guide to the organization of the needs and priorities it identified. This outline appears as Table 1.

Table 1

USES OF BIOLOGICAL MONITORING

1. Indicator of effects
    a. real time detection alarm system
    b. community ecosystem impacts
2. Indicator of presence of pollutants
3. Measurement of exposure through foodstuff or nutrient supply
4. Indication of exposure by all routes
5. Assessment of dose to target sites

Having constructed its outline, the Committee decided to allow each of its members to present an individual list of needs and priorities. These presentations were discussed at length. Some were dropped from consideration, and some were combined with others. The recommendations that the entire Committee supported were subsequently organized into five major categories:

1. Selection and Documentation of Bioindicators
2. Areas for Expanded Use of Biological Monitoring
3. Development of Bioassays for Environmental Samples
4. Evaluation of Microcosms as Simulators of Real Environments
5. Policy Recommendations

The first four categories are clearly within the Committee's charge and the fifth includes concepts and applications essential for any utilization or understanding resulting from attention to the first four.

While the Committee considers all of the research needs and policy recommendations in this Report crucial, it urges that special attention be given to the recommendations involving cost effectiveness. Some of the Committee members believe that microcosms warrant a relatively low ranking on a cost-effectiveness basis. The entire Committee recognizes this dilemma: The larger, more natural, and therefore, more realistic a microcosm is, the more expensive it is to study.

The recommendations themselves appear sequentially, numbered 1 to 17, throughout this Report. The statements of the recommendations sometimes include discussion and are sometimes preceded by and separated from the discussion. The Committee adopted whichever approach seemed clearer and more logical.

II. Selection and Documentation of Bioindicators

A. Determination of Statistical Variability

(1) We need to validate biological monitoring methods by determining the amount of statistical variation that would be encountered across the spectrum of monitoring situations. Such sources of variation as inter- and intralaboratory variation, variation among members of the utilized populations, and variation attributable to environmental factors impossible to standardize in the routine application of the monitoring method must be quantified. These estimates of variability control the validity of a monitor in any specific application. The error rate of false-positive and false-negative responses is directly affected by these variations; thus, we need to know them in order to assess the value of a monitor.

B. Determination of Possible Threshold or Quantitative Response Drifts

(2) Biological monitoring methods must be validated by an investigation

of the possible drifts in the average threshold level that triggers a response, or drifts in the quantitative response to a fixed level of exposure. Since biological monitors rely on biological organisms as the receptors or indicators of substances of concern, prolonged, low-level exposure could cause an evolutionary (adaption or sensitization) drift, or a change in either the threshold causing a response or in the response itself, if it is quantitative. We must either conduct studies to determine whether these phenomena occur with a particular monitor, or devise methods to calibrate a biological monitor in a fashion that removes the drift.

III. Areas for Expanded Use of Biological Monitoring

A. Biological Monitoring Used in the Recovery of Disturbed Ecosystems

(3) Conservationists too often present pictures of environments lost to pollution without publicizing environments regained. Recoveries of such areas as Lake Washington in Seattle and the upper Mississippi River below the Twin Cities are little-known but remarkable examples of recovery from excessive degradation. There is a real need for the public to understand how communities exposed to various pollutants do or do not recover. Scientists, too, must understand the recovery rates of those ecosystems exposed to various kinds of pollutants. Such insight would help us make better judgments regarding the risks inherent in exposing specific ecosystems to various kinds of pollutants. The public may be better able to accept the degradation of some ecosystems for short periods to obtain the benefits that might not be gained otherwise. Without such an understanding of ecosystem recovery, conservationists, industrialists, governmental agencies, and the public are often at swords' point.

B. Biological Monitoring to Assess Economic Impact

(4) We have yet adequately to gauge the magnitude of the economic impact of air pollution on agricultural and timber crops. While laboratory research has been directed at understanding the fundamental effects of pollutants on

plants, we cannot yet apply these findings to field evaluations of impact on yield and growth. The presence of foliar air pollution injury in the field does not necessarily indicate that economic impact will occur. The integration of such factors as the plant species, the severity of the injury, the stage of growth at which injury occurs, the portion of the plant that comprises the crop, and the plant's growth pattern will ultimately determine whether an economic impact occurs. Field observation combined with laboratory research is currently inadequate to an understanding of the integration of these factors and a determination of the potential impact on yield and growth. In addition, researchers have shown that plant growth and yield can be affected by pollutant levels below those required to produce external signs of pollutant impact.

Any assessment of the influence of pollution on plant yield and growth should be conducted in the field over the course of an entire growing season and the experimental design should allow the effect of air quality to be clearly isolated. These objectives can be most adequately attained through the use of filtered and nonfiltered open-top air chambers. This technique has been used successfully by several researchers and can be employed with a wide variety of plant species. It allows a researcher to estimate the impact of air quality on productivity and, consequently, to assign an economic value to the impact. The expanded use of this technique will provide definitive data on the economic impact of decreased air quality. This assessment can then be incorporated into a larger cost-benefit analysis to evaluate the potential advantages of improved air quality. Only through approaches like these can we ascertain highly specialized economic consequences.

C. Target-Site Dose Assessment

(5) We must develop methods for detecting the exposure of a target organism to a pollutant or class of pollutants and of estimating, directly or indirectly, the critical dose for that organism.

An estimate of the effective dose to the target site is essential, initially to establish exposure-dose and dose-effect correlations. But in the context of biological monitoring, the use of the target organism as its own dosimeter permits a direct quantitative prediction of potential harm.

D. The Establishment of Specimen Banks

Once a system has been affected by man's activities, it may be impossible accurately to depict the character of that system prior to impact. Thus, an accurate assessment of impact may be confounded by the lack of historical data against which current system characteristics can be measured. Specimen banks can help overcome these problems. These banks are, simply, collections of samples from systems stored for future analysis should the need arise. They are repositories of historical information ready to be tapped. Since it may not be evident at the time of collecting what element, compound, or other parameter may be of future interest, the entire specimen should be stored without immediate analysis. If the need arises, the specimen can be retrieved and analyzed for the particular factor of concern.

These specimen banks should be established for the human, aquatic, terrestrial, and abiotic components of systems of potential concern. Storage procedures and costs will vary considerably, depending on the sensitivity of the material. While the short-term benefits of such a banking system may not be fully evident, these repositories can serve as major sources of historical data on system parameters in the more distant future. Once these specimens and their historical data are lost, however, they can never be fully recovered.

(6) In light of this discussion, the Committee believes that the Environmental Protection Agency should establish specimen banks to provide background data with which to compare future biological monitoring data related both to levels of pollutants in the environment and to their effects. The availability of properly stored human and environmental samples for retrospective analyses would (a) enhance estimates of levels of substances for

which current analytical techniques are inadequate, and (b) provide data for confirming or refuting health effects allegedly attributable to pollutants.

E. The Establishment of Bioindicator Catalogues

(7) The Committee believes that an encyclopedic catalogue of bioindicators should be available, with information on toxic accumulations in sensitive species. For each species, whether indigenous or introduced, the catalogue should include a complete documentation and references as to which pollutants cause an effect and the nature of that effect. Relevance determination studies and the validation of the results should be cited and reported for each species and each effect. For this material to be easily accessible, moreover, an extensive cross-reference should be organized by effect and pollutant.

F. Biological Monitoring of "Socially Acceptable" Environmental Deterioration

One long-term goal of the EPA's activity is presumably this: When society's base requirement of goods and services reaches the point at which standards of environmental quality must be relaxed to permit increased production, the appropriate kinds and amounts of information should be available to permit sound decision making by the officials responsible. More comprehensive and exact knowledge of biological responses to higher levels of environmental perturbation will be required to establish more definitively the levels of environmental deterioration man can tolerate.

Society's willingness to accept a reduced standard of living as a cost of improved environmental quality or to accept greater environmental deterioration as a cost of providing the essentials seem to be receiving little concerted research effort. There seems to be a similar void in research directed to the minimum levels of goods and services essential for the maintenance of social well-being. The EPA may feel that it is already overwhelmed by requirements to meet existing statutory mandates without pursuing the social research required to resolve such questions as these. Indeed, entirely new methodologies will probably be required before such research can be undertaken. But unless both sides of the risk-benefit equation are documented with similar precision, the reliability of the decision making may well be open to question.

(8) Consequently, the Committee believes that we should determine (a) the level of environmental degradation society will tolerate in order to satisfy its desire for goods and services, and conversely (b) the reduction in living standard society will accept in return for improved or stable environmental quality.

G. A General Justification for Biomonitoring

(9) Biomonitoring is essential to both the research and regulatory arms of the EPA. In the research area, it opens the possibility of monitoring process streams over long periods in order to assess the impact of process variation on public health. Used properly, biomonitoring can act as a public health hazard early warning system. In addition, biomonitoring is the only way to determine the specific organ or organism targets of environmental contaminants, and it is the only means of determining what part of a complex sample is being retained so as to effect an adverse response and cause public health concern.

IV. Bioassays of Environmental Samples

A. Short-term Bioassay Techniques

Most traditional toxicological methodologies are too lengthy and costly to be practicable when applied to the complex mixtures found in the real environment. But the short-term *in vitro* tests now in wide use do not yield data that permit a development of quantitative risk assessments. Nevertheless, the EPA offices responsible for setting regulations place a high priority on these quantitative assessments.

(10) In view of these facts, the Committee suggests that the EPA place more emphasis on those (relatively) short-term bioassay techniques capable

of yielding quantitative estimates of potential harm to man and other species. Specific human outcomes to be addressed include cancer, cardiovascular disease, behavioral dysfunction, birth defects, reproductive dysfunction, and immunological system dysfunction.

B. A General Bioassay Justification

The bioassay techniques used in the initial screening of complex environmental samples provide an early assessment of a pollutant's potential public health impact. But limited resources and manpower preclude complete biological analyses on all potential sources of concern.

(11) The Committee recommends, therefore, an emphasis on quantitative bioassay techniques in order to direct the EPA's regulatory and data gathering activities more expeditiously. We need research aimed at providing quantitative bioassay techniques in addition to the qualitative techniques that presently exist.

V. The Evaluation of Microcosms as Simulators of Real Environments

A. Microcosms as Determinants of Toxicity Levels

(12) The development and study of microcosms encourage an understanding of the relationship between acute toxicity bioassays and what happens in the pollution of natural systems. Acute toxicity tests are necessarily short and physiological in nature. Their objective is to determine at what toxicant level and during what period 50 percent of the experimental population dies.

But we ought to be more interested in how a population responds to a chronic level of toxicity: how the population may suffer through impaired reproductive capacity, in the care of its young, in feeding, etc. If the organism is not able to complete its life cycle, even though it does not suffer mortality, the species can be destroyed. Therefore, the use of microcosms provides a means of matching as much of the natural environment as possible with low levels of toxicity to provide a gauge of long-term chronic effects.

B. A General Microcosm Justification

(13) Microcosms form a bridge between laboratory analyses of environmental samples and on site (in situ) biomonitoring activities. Microcosms provide the only means currently available to simulate actual environmental conditions while allowing investigation into the most significant contaminants in a sample.

Current research at the EPA laboratories in Corvallis, Oregon, Gulf Breeze, Florida, and Narragansett, Rhode Island, has demonstrated the feasibility and utility of microcosms on at least a limited scale (American Statistical Association, 1978a). Additional effort should be directed toward applying these systems to real environmental stresses and contaminants.

VI. Policy Recommendations

A. Comparing the Cost Effectiveness of Biological Monitoring Methods to Chemical and Physical Methods

The ability of society and those government agencies representing society to utilize any recommended biological monitoring approach, method, or technique will depend largely upon its cost. Even if a method were scientifically sound and desirable, it would have to be affordable as well. The decision to use or not to use any particular method must be based on whether the benefits derived are equal to or greater than the cost.

Certain methods that are scientifically useful and relatively inexpensive may not appear to warrant any cost-effectiveness analysis. Nevertheless, the analysis is always done, though it may occasionally be done subjectively.

(14) Some methods implied by the Committee's recommendations are liable to be expensive (for example, microcosm development). Cost-effectiveness analysis is, therefore, imperative. But the Committee recommends cost-effectiveness analyses for all biological monitoring methods relative to chemical and physical methods. Additionally, we recommend comparisons of

biological methods among themselves. In these processes, one should keep continually in mind that certain biological methods may provide specific benefits and information totally unavailable through chemical or physical methods. In such cases, a high cost could be justifiable.

B. Measures of Uncertainty in All Monitoring Reports

(15) The results of monitoring programs (biological, physical, or chemical) should be reported with the appropriate measures of uncertainty clearly delineated. Data from monitoring programs are obtained by sampling the environment over time and space and measuring these samples with a variety of techniques. Both the sampling and the measuring can introduce errors. An informed consumer of this information must be able to gauge its accuracy in order to formulate policy or make decisions based on the data. In many situations, the appropriate policy decision should be to collect more and better data before taking action. Only measures of uncertainty accompanying all reported results can assure that this option remains open.

C. Individualized Data Storage and Retrieval Systems

(16) Data storage and retrieval systems should be tailored to the immediate objectives and needs of a particular project. The goal of constructing an ultimate data storage system that contains data from virtually every project may be attractive, but it will inevitably lead to less quality control in the collection and storage of the data. By individualizing storage and retrieval (a) better control of the quality of the data can be maintained, (b) data file specifications can be more easily adapted to the development of new methods, (c) the ownership of and responsibility for the data becomes visible and therefore more reliable, and (d) excessive expense occasioned by the large size and complexity of a single large data bank can be avoided.

The Agency can best meet its data requirements by stipulating that all project data be properly documented and stored in machine readable form.

These documentation requirements should, moreover, focus more on the quality of the data than on the ease of its storage and the convenience of its retrieval (American Statistical Association, 1978b).

D. The Allocation of Funding for Novel Research Approaches

Every advance in human history has been based upon what was once a private opinion. This is so in science as well as in all other fields of human endeavor. A recent issue of Nature (April 5, 1979, p. 493) made some cogent observations on the decline of science in Europe: "Rigidity, resistance to innovation, personal immobility--these are the constraints that keep Europe from responding flexibly to a changing world."

(17) In all endeavors, the individual with unique qualities of perception and innovation must have opportunity. Funds should be made available to a few truly outstanding researchers. These kinds of minds should be encouraged to examine novel approaches to old problems. Industry recognizes the importance of such people; so should the EPA.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
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Measurement and Analysis of Sources and Ambient Levels

April 23 and 24, 1979

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MEASUREMENT AND ANALYSIS OF SOURCES AND AMBIENT LEVELS

I. Introduction

The Committee on Measurement and Analysis of Sources and Ambient Levels has divided the balance of this Report into five principal sections: "An Overview of Managerial and Organizational Needs," "A Discussion of Research Approaches," "Measurement Needs Related to Regulatory Programs," "Measurement Methodology and Data Analysis Research Needs," and "Summary Recommendations Addressing Broad Issues and Concerns."

While three of the five principal sections contain lettered subdivisions, the Committee has presented its recommendations, numbered 1 to 35, sequentially throughout its Report.

The final section, "Summary Recommendations," presents nine recommendations (27 through 35) that state in general terms specific recommendations that appear earlier in the Report. While the Committee has not arranged its recommendations according to any agreed-upon priority, these final nine do represent the recommendations the Committee wanted to stress.

II. An Overview of Managerial and Organizational Needs

One of the conditions that makes it difficult for the EPA to develop a strong and viable research support program is that the EPA is, first and foremost, a regulatory agency. It is not research oriented, and it appears to have a problem distinguishing between research and monitoring, two distinctly different functions conducted in different ways. In fact, one cannot expect a balanced research program to evolve when program emphasis and resource allocations are mandated or strongly influenced by interest groups outside the Agency.

(1) Consequently, the Committee sees a need for the EPA to develop a comprehensive research program with specific, long-term objectives. In depth,

long-range planning is necessary to provide meaningful data for decision making. But this approach contrasts with the current policy of seeking quick solutions to immediate problems.

(2) The EPA should include in its long-term research not only the studies obviously needed currently, but also anticipatory research that will help us collect data in advance of its need for a specific purpose or emergency. Such data availability would enable the Agency to respond much more efficiently and effectively to conditions as they arise.

(3) The research program should be separated from and conducted independently of the monitoring programs. These programs are now too closely allied, and problems arise both within and outside the Agency in separating the bonafide research from the routine collection of data (monitoring). The Committee believes this separation to be very important. It can be accomplished in at least three ways:

(a) Within the Office of Research and Development, a separate and autonomous group could be established whose sole responsibility is to conduct research and to evaluate or summarize findings.

(b) The research could be contracted to other scientists, besides simply those at the EPA, whose reputation and reliability are known and accepted. These data would provide EPA values to use to establish tolerance levels, limits, or guides for developing regulations.

(c) The research could be directed from the Office of Research and Development within the EPA but carried out, unilaterally or collaboratively, by multi-agency arrangements. For example, water research might be augmented by the U.S. Geological Survey, soil research by the U.S. Department of Agriculture, toxic materials work by the Food and Drug Administration or the U.S. Department of Health, Education and Welfare, and so forth.

All research, regardless of where it is conducted, would be assembled and evaluated by the EPA.

(4) Currently, we see a serious link missing between the generation of research data and its application by the regulatory offices. The Committee strongly urges that a permanent staff of professionals be assembled whose duties are to translate research findings into meaningful information for use by the regulatory personnel. The office should be staffed with individuals with research training yet fully cognizant of the needs and limitations of regulatory functions.

III. A Discussion of Research Approaches

A. General Needs

(5) Before standards are established, we must know the background levels of substances in air, water, soils, and the biosphere. Such levels are highly variant both spatially and in time. At present, we have inadequate data about this background, or the so-called residual or ambient levels. Without such information, standards cannot be intelligently set or enforced, nor can pollutant levels be reliably identified and quantified. Moreover, we must learn how to translate our current scientific understanding of complex natural ecosystems and toxicity into scientifically defensible as well as economically realistic standards.

The following sections present more specific recommendations regarding the physical and biological media.

B. Air Needs

(6) The impact of uncontained (fugitive) sources on ambient air quality must be more quantitatively defined.

(7) We need a more comprehensive chemical characterization of sources of pollution, and we should require ambient samples for organic and inorganic materials.

(8) We should investigate natural sources of pollution to determine their impact on ambient levels in both "clean" and "polluted" areas.

C. Water Needs

(9) The EPA should make a greater effort to characterize ambient conditions, particularly as related to surface and ground waters. This effort should include characterizing surface waters by climate, watershed, geology, and land use. Studies should be made of ground water background quality in the context of local and regional geology, rock types, soil types, and other specific natural controls. Such characterizations should include studies of how storms and seasonal effects cause variations in background quality. Information on the background quality of ground waters from different rock types and aquifer systems should be collected and generalized statistically.

Most of the data necessary to accomplish this effort now exist in the files of the Water Resources Division of the U.S. Geological Survey. But the major problem of characterization today is in the area of toxic chemicals, particularly from industrial and mineral waste.

(10) The Agency should endeavor to distinguish organic and inorganic species in surface and ground water that are characteristic of either pristine or polluted influences, and it should learn what amounts of species common to both sources are typical of the natural contributions.

(11) Water quality data from small public supplies should be collected, and if of suitable quality, incorporated into the Storage and Retrieval of Water Quality (STORET) system. (The Committee wonders if the initial goals of the Comprehensive Waste Water Management Program (COWAMP) have, in the opinion of the EPA, been attained, and what has resulted from these programs, originally designed to provide adequate data on the pollution sources and ambient levels in surface and ground waters.)

(12) We need to learn how to translate our current scientific understanding of controls on the toxicity of substances in water into realistic and scientifically defensible standards.

(13) We should learn to identify the detailed controls on the toxicity of stream quality and its effect on fish with more precision. The present simple numerical standards for heavy metals tied to water hardness are scientifically indefensible.

(14) Because current research shows that the chemical activities of metal ions and some metal complexes, not total metal amounts, are chief agents of toxicity, we must develop methods of determining such metal activities in water. These methods may be electronanalytical, or based on computer calculation. Computer programs to make such calculations are now generally available among research geochemists and sanitary engineers. The programs should be employed, along with specific ion electrodes, in studies of toxicity to aquatic life.

(15) The Water Resources Division of the U.S. Geological Survey in Denver and Menlo Park is involved in a program to develop routine methods for characterizing organic compounds in water by their function as metal complexers. This research is directly relevant to an understanding of toxicity effects and should be incorporated in a collaborative research effort involving the EPA. (The Committee notes that the application of the concept of "prevention of significant deterioration" to the preservation of ground water quality influenced by industrial, including mining, activities must be seriously questioned when such constraints are applied to ground waters which, in their natural state, are of no practical use in the first place.)

D. Soils and Land Disposal of Wastes

(16) The use of soils and other geologic materials as media for the ultimate disposal of various effluents, sludges, fly ash, industrial wastes including chemicals, and radioactive materials is becoming increasingly common. We must pay increased attention to the long-term effects of

using geologic materials as waste sinks. We need more specific information to ascertain what geologic, topographic, and soil conditions constitute acceptable risks and so avoid aggravated soil and ground water pollution problems.

E. The Biosphere

(17) The relationship between the existence of toxic substances in the physical environment and their appearance in the food chain and in animal tissues remains largely uninvestigated. We know little about the entry of such residuals from soil, air, and water into animal and plant tissues, about how these substances may be modified as they pass through the biosphere, and about their potential impact on ecological well-being. Research efforts should concentrate on a comparative analysis of various residuals in air, water, soil, plant, and animal tissues. Further studies should evaluate how the pollutant is modified as it moves through the food chain.

Our current methods cannot correlate analyses of toxic substances in food and biological specimens with air and water analyses. We should, therefore, develop rapid and reliable methods for analyzing food contaminants and concentrations of residuals in biological specimens.

IV. Measurement Needs Related to Regulatory Programs

The Committee did not give major consideration to needs of the Agency's regulatory program. But some important, recurring concepts appeared during the discussions of research needs.

(18) The Committee feels that the primary need in this area is the implementation of a specific program to modify and transfer the measurement technologies utilized in research studies to the regulatory process. Too often, outmoded and sometimes inappropriate measurement methodologies are promulgated for regulatory purposes even when research shows that superior methodologies exist. This tendency reflects a failure to perceive

that significant modifications must be made in research measurement procedures--certainly of air; perhaps to a lesser degree of water--before they can be demonstrated to be reliable, economical regulatory tools.

(19) The EPA's activities in quality assurance and quality control need to be strengthened. While the EPA has already instituted data quality programs, these programs need to be more formally structured within the agency and given adequate resources and management support. The EPA should seriously consider certifying laboratories performing environmental measurements of regulated pollutants.

V. Measurement Methodology and Data Analysis Research Needs

A. Discussion

To be meaningful and defensible, monitoring and enforcement activities need (a) conceptual and philosophical bases, (b) a theoretical framework, (c) methodological support, (d) technological tools, and (e) administrative management. It is very important to identify and integrate the specifics of these important factors responsible for protecting the environment. We live in an age of an informational paradox: we have an excess of information in general and too little information in particular. We often face the issues of comprehensive versus comprehensible information.

(20) In order to achieve suitably economical study designs, and the collection and evaluation of scientific data, the EPA must support research on measurement methodology and data analysis. This information would allow the EPA to continue beyond measurements to conduct analyses directed toward responsible intervention.

B. Quantitative Methodologies Needing EPA Research Support

In recent environmental work, the methods listed below have been found to be useful. Standard versions of these methods are available in the quantitative literature, but different versions designed for fruitful environment research and management should be developed. This development would permit meaningful retrospective studies and would also help provide useful analytical tools:

(a) Measurement Process and Related Instrumentation;

(b) Measurement Process and Related Quantitative Methodology;

(c) Environmental Sampling Methodology, such as Transect Sampling and Composite Sampling;

(d) Spatial and Temporal Analysis;

(e) Multivariate Methods for Species Abundance and Community Structure;

(f) Experiment Design and Surveys;

(g) Transport Processes and Diffusion Analysis; and

(h) Data Processing and Data Management.

(21) The EPA should require the basic and applied research teams it supports to correlate their progress with the ongoing monitoring data sets or available data sets collected under the aegis of the EPA in the first decade of its existence. The research in measurement methodology and data analysis linked with measurement technology and empirical research might prove immensely useful. But it would also be essential to provide an effective collaborative research mechanism and training workshops. The Satellite Program in Statistical Ecology of the International Statistical Ecology Program may provide a prototype.

(22) Thus, we urgently need adequate support for (a) methodological research involving real data sets, and (b) collaborative research and training workshops in quantitative studies and issues for 1981-1985.

C. Specific Measurement Methodology Research

The Committee identified four specific measurement research needs during its discussions. Rather than enumerate these in detail for each media, we have grouped them into general needs that relate to all media, then synthesized them into the following broad categories.

(23) Screening methodologies. The present emphasis on looking for "lists" of compounds of concern or relying on specific analytical tools leaves many gap areas in our knowledge of source and ambient pollution. We need a rational protocol that provides some minimum level of knowledge about characteristics of total samples. The protocol should not be based on lists or specific analyses but rather on data needs. It should allow one at least to "infer" the maximum concentration of various compounds that might be present.

(24) Bioassays. We know that chemical composition cannot be used to define the potential biological effects of pollutants. We need to develop low cost, rapid bioassays that can be used in conjunction with chemical characterizations, especially for complex samples. To make effective use of data, we also need a planned program of coordinated interpretation of data by the chemical and biological communities.

(25) Fugitive emissions. The impact on ambient levels of pollution from "uncontained" sources is now recognized as a major problem, and the measurement capability for determining the characteristics and mass flow of pollutants from uncontained sources requires considerable development.

(26) Geologic compositions. Current research by geochemists in ore-deposit exploration and chemical oceanography, for example, has focused on identifying the nature of toxic metal associations in soils and sediments. For example, methods are being developed selectively to distinguish how and where a given metal is associated with organic matter, sorbed on oxides or clays, or is found within silicate or sulfide mineral structures or in associated waters. Because toxicity and mobility of metals depends on their form of occurrence, such techniques of characterizing metal occurrence can have a direct application in the appraisal of particulate air pollutants, soils, and other geologic materials. The

EPA should initiate research to perfect and apply such methods to characterizations of solid wastes, soils, and other materials.

VI. Summary Recommendations Addressing Broad Issues and Concerns

A. Measurement Methodologies

(27) The EPA should attempt to adapt current measurement methodologies to its regulatory activities.

(28) Measurement methodologies for screening, bioassays, fugitive emissions, and geologic compositions should be refined.

B. Quantitative Studies and Issues

(29) We urgently need intensive collaborative research with intensive research seminars on quantitative studies and issues.

(30) We must have adequate support for research into statistical and mathematical methodologies that focus on real data sets. Immediate attention should be given to environmental sampling methodology, spatial and temporal analysis, species abundance models, and the measurement of community structure parameters.

C. Sources and Ambient Levels

(31) We need better characterization of residuals or background levels of both natural and pollutant species in air, water, soil, and biosphere systems. Whatever information is already available from inside and outside the EPA should be fully utilized.

(32) Standards for water quality can and should be updated in the light of current research results.

(33) We need more research to characterize ground water resources. Such research should address the preservation of ground water quality and the establishment of scientifically sound standards for ground water quality.

(34) We should better understand the movement of various pollutants

into food chains and animal tissues.

D. Management and Organizational Goals

(35) The EPA needs long-term goals and carefully identified research objectives, anticipatory research, research programs independent of monitoring programs, and an effective linkage between its research and regulatory programs.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

The Ultimate Disposal Aspects of Environmental Protection

April 23 and 24, 1979

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THE ULTIMATE DISPOSAL ASPECTS OF ENVIRONMENTAL PROTECTION

I. Introduction

"Ultimate disposal," as an acceptable environmental protection program, consists essentially of three options: First, the environmental control aspects of many materials may be minimized by the development of recycling and secondary use programs; second, materials may be destroyed or detoxified and satisfactorily redispersed into the environment; and third, materials may be contained and stored for extended periods.

Four laws, The Clean Air Act, The Clean Water Act, The Resource Conversion and Recovery Act, and The Toxic Substances Control Act, pertain to ultimate disposal as an environmental protection program, and provide the U.S. Environmental Protection Agency with the authority to implement this program.

Because an appreciation of the significance of ultimate disposal as an important environmental protection need has come only recently, significant amounts of innovative research are required in order for the Environmental Protection Agency to fulfill its ultimate disposal mission effectively.

II. Discussion

The Committee feels that the EPA's role falls principally within two areas: (1) the development of new technologies to make it technically possible to implement all approaches to ultimate disposal as defined earlier; and (2) the development of an improved understanding of the effects of existing and needed economic and regulatory incentives and restraints in the selection and implementation of satisfactory approaches to the ultimate disposal of potential pollutants.

In addition, the Committee feels that to carry out a successful ultimate disposal research program, the EPA must possess the appropriate tools for the task before it. Its specific deficiencies include (1) the lack of an independent research budget; and (2) inflexible procurement policies, which stifle innovative approaches to solving environmental problems initiated external to the EPA.

The Committee recommends that the EPA's research efforts be directed to these three general aspects of "ultimate disposal," and in this order:

(1) recycling and secondary use approaches;

(2) destruction, detoxification, and redispersal approaches; and

(3) containment and long-term storage approaches.

Furthermore, while the third approach enjoys the greatest historical precedent, and will continue to be used extensively in the future, it is the least desirable approach, and every effort must be made to develop technologies that encourage the use of the first two approaches.

The EPA should also improve its ability to discriminate among levels of hazard represented by various potentially polluting materials. The present legislation does not appear to reflect this capability. Thus, one principal research project might be to improve the methodologies that quantify the extent of a hazard and establish criteria that correlate hazard levels with the optimum disposal method consistent with the overall objectives of recycling and reuse.

III. Recommendations

The Committee feels that the following specific topics should be included in the EPA's "ultimate disposal" research program. The three topic categories are lettered A, B, and C. The recommendations themselves are numbered sequentially, 1 through 12, throughout the topics.

A. Recycling and Secondary Use

(1) Incentives and economic, regulatory, and technological "disincentives" (or restraints) imply choosing an ultimate disposal technology that balances between direct cost and overall environmental acceptability. To

ensure that adequate weight is accorded environmental acceptability, we must improve our knowledge of all existing incentives and disincentives. New incentives may also be required. Typical areas of consideration could include land title conveyance prohibitions, subsidized waste exchanges, direct taxes, permanently dedicated land use, regulation, and improved technologies.

(2) Proper land application at or near the surface requires a knowledge of technique capability in the following areas: (a) the types of waste which may be used; (b) types of terrain, geology, and soils; (c) land use conflicts; (d) alternatives to individual and community septic tank systems; (e) the management and design of land application; (f) food chain impact; and (g) ecosystem impact. This technique should be emphasized where waste characteristics complement soil nutrient requirements.

(3) Energy recovery applications require knowledge in the following areas: (a) waste modifications so that the waste may be acceptably confined in existing borders; (b) waste modification so that it may be burned in special-purpose systems; (c) the design and operation of special-purpose boilers; (d) the development of special-purpose boilers (special controls and heat recovery systems); (e) an assessment of fermentation as an acceptable technique; and (f) an assessment and development of pyrolyses, gasification, or liquification techniques as may be offered to the EPA through program opportunity notices or unsolicited proposals.

B. Destruction, Detoxification and Redispersion Into the Environment in an Acceptable Manner

(4) Acceptable incineration implies the following research needs: (a) the efficiency required and control development necessary to achieve the appropriate pollutant destruction levels and to optimize the use of supplemental fuel; (b) the development of improved operating controls like temperature monitors and area flow and leak control; (c) the development of fail-safe systems; and (d) small-scale and pilot test and analysis capability.

(5) The EPA should encourage the development of chemical inerting programs so that toxic materials and other pollutants may be redispersed into the environment.

(6) The EPA should encourage the development of whatever biological inerting programs it considers appropriate.

(7) The EPA should reassess dispersion as a direct ultimate disposal technique, and include a reassessment of the need for and ultimate effectiveness of conventional control programs--both as an approach and regarding the level of control required. (For example, the Agency should examine the impact of tall stacks versus scrubber sludge disposal on the environment and on-site sewage disposal versus sewering.)

C. Containment and Long-Term Storage

(8) The effect here on landfills requires a knowledge of (a) the appropriate materials and criteria; (b) the appropriate locations; (c) optimum design, construction, and long-term maintenance; and (d) leachate control and treatment--for example, leachate from urban waste landfill as a hazardous waste.

(9) The encapsulation and incorporation of the waste into a matrix requires (a) that the EPA define the benefits of large versus small particles with regard to pollutant release rates; (b) a definition of appropriate materials; (c) that the EPA contract for the testing of various encapsulation or matrix-forming techniques; and (d) a definition and demonstration of suitable storage or secondary use of encapsulated waste. (For example, one could subsidize the effective use of wastes as ingredients in road bed construction.)

(10) Long-term, controlled entombment (the last resort) requires (a) an appropriate or "no choice" materials definition; (b) an appropriate site definition; and (c) optimum construction and site integrity maintenance techniques.

(11) The use of deep well injection techniques requires the EPA (a) to define appropriate materials for this type of disposal; and (b) to select criteria for siting deep well disposal facilities.

(12) The development of adequate monitoring programs requires the EPA (a) to improve on-site monitoring and spill warning systems; and (b) to improve remote sensing techniques for area monitoring.

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Incentives and Framework for Control

April 23 and 24, 1979

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INCENTIVES AND FRAMEWORK FOR CONTROL

I. Introduction

The Committee on Incentives and Framework for Control organized this Report by prefacing its actual recommendations with a series of individual sections that collectively show the pattern of the discussion that led to those recommendations. Thus, the major section that follows has been headed "Discussion" and includes a total of 17 sub-sections lettered A through Q. The Committee's recommendations, numbered 1 through 10, appear under a major heading at the conclusion of this report.

II. Discussion

A. The Role of Emissions Taxes on Environmental Policy

Many economists prefer such financial pressures as emissions taxes to direct regulations like pollution control policies. They give several justifications. First, the charges are presumably imposed without qualification so that the tendency to procrastinate, to seek legal relief, and to resist research expenditures are lessened.

Second, the choice of abatement strategy is left to the regulated entities. The organizations possess expertise about the relevant technical options that the regulators do not necessarily possess and are unlikely to obtain. Thus, those best informed about the relevant technology must effect the implementation.

Third, the process of setting a tax forces a regulator to examine more fully the benefits and costs of the policy. And fourth, while under regulation, the sources tend to do just what is required of them and no more. Where taxes are imposed, rewards accrue to those who employ technologies that improve upon the standard.

Theoretical analysis suggests that a tax is preferable to a subsidy for several reasons. Primarily, it is difficult to determine who warrants subsidization and easy to claim subsidies that are undeserved. In addition, a broad consensus holds it more equitable to force those who avoid abatement to bear the costs. The theoretical support for these arguments can be found in an enormous literature and needs no further review. What we do need is an examination of the practical relevance of these principles to specific environmental policies. Almost any area of existing and prospective regulation could fruitfully be appraised to determine the relative practical merits of financial incentives compared to the various regulatory strategies actually employed. Another area for possible work would be a study of imaginative environmental programs in other countries.

Some areas seem to have received more attention than others. For example, water pollution control policy and mobile source air pollution policy have been thoroughly studied. But, as we will soon discuss, some attention might be given to alternative strategies for implementing the existing goals in auto emission control.

A primary area of concern is stationary source air pollution policy. The Committee has noted at least three major sub-areas of this concern, and the EPA could probably identify others. First, a major program has existed to control sulfur oxide emissions, with the principal problem stemming from coal-fired electric power plant emissions. Various environmental groups, the electric utilities, and the coal industry have all criticized the policies in this area. Thus, it would be highly desirable to examine dispassionately the comparative merits of emission charges, ambient air standards, emissions control from specific sources, and control of emission technology choices.

A second fruitful area of study would be petroleum refining. It might, in fact, be appropriate to consider comprehensively all the pollution associated with the entire petroleum industry. A variety of land, air, and water pollution problems arise from producing, transporting, storing, refining, and using petroleum and its products. Considerably more work could be done to develop an integrated approach to pollution control in the petroleum industry. Such work might include the characterization of pollution problems, an examination of the policies developed to deal with these problems, and a review of the state of abatement technology. The material could be synthesized into an appraisal of how these policies might be integrated into a more effective program.

A third example of possible concern is coke oven emissions. Here again, the effects of interaction arise; specifically, industrial health as well as air pollution problems appear. The difficulty of dealing simultaneously with the interaction among pollution problems requires further review. It has been widely noted that reducing one form of air pollution may increase emissions of another pollutant, but few researchers have investigated the implications of this phenomenon. Similarly, a solution to pollution may aggravate land or water problems. Still other areas needing closer review include land use and noise control.

U.S. researchers have cited European efforts to employ emission taxes, but they have apparently not closely examined those efforts. A natural starting place for examining the state of knowledge on these policies would be the Environmental Directorate of the Organization for Economic Cooperation and Development (OECD). Therefore, the Committee suggests that the EPA contact OECD to determine what materials are available and then consider supporting research on policies that seem of interest.

B. Better Characterization of Health Benefits

To provide an incentive to carry out federal regulations, the EPA should establish a more accurate data base on which to base regulations. An inadequate data base encourages disagreement with policy, disrespect for the Agency and law, and widespread uncertainty within the general public and industrial sector. Thus, solidifying this data base should be of enormous importance to the EPA. The inadequacy of our environmental pollutant data base stands out most dramatically when we must identify and quantify those individuals who risk significant adverse health effects from pollutant exposure before the general population does. This information gap is especially important in view of the fact that the incorporation of high-risk groups in the regulatory process may result in a significant shift in currently accepted dose-response relationships. Thus, the Committee recommends that research efforts be directed toward defining more precisely, via animal models and epidemiological research, the effects of toxic substances on high-risk groups. The concept of increased risk should be considered quite broadly and include all developmental, genetic, nutritional, pre-existing disease conditions, and life-style variables that may enhance susceptibility.

C. Analyzing the Benefits of Pollution Control

Analyses of the value to society of pollution control remain primitive. While the fundamental problems are deficiencies in the knowledge about the basic natural, scientific, and engineering questions, problems in the social-scientific realm must also be faced. The bulk of the research on developing monetary measures of pollution control benefits has been conducted by non-governmental researchers, often with non-governmental funds. We need considerably more work in this area. At least a limited amount of study should focus on the theoretical problems of quantifying the benefits of pollution control. But our primary need is for a continuing program of applied social-scientific inquiry into the monetary benefits of controlling all forms of pollution.

D. Incentives for Automobile Emission Control

The current program in the U.S. to curb automobile emissions requires catalytic converters on autombile exhausts. At present, we see no effective implementation of this program, and many of the control devices simply do not function. We should determine why these devices are not operating:

Are they technically inadequate? Are they being tampered with by the owners? Or are they rendered inefficient by the use of leaded gasoline? If the last suggestion explains the inefficiency of the converters, incentives should be considered to eliminate the use of leaded gasoline--for example, by placing an excise tax on leaded gasoline to make it as expensive as unleaded gasoline.

To see that the controls already in existence operate properly, some states have initiated implementation plans. Accordingly, we should learn whether it is more effective to make these statewide plans, or to enforce them only in the large urban areas with oxidant problems. Should the programs require periodic inspections? or levy fines on automobiles found not to comply with standards? or place other sanctions on the owners of automobiles not operating properly?

E. Prospects for Decentralizing the Administration of Pollution Control

A degree of federal control seems to ensure that the states do not allow dangerous levels of pollution in order to attract industry. It also seems to ensure that the interstate effects of pollution are considered. But issues do arise about the proper balance to be maintained among federal, state, and local governments in implementing regulations. We suggest an inquiry into the possibilities of decentralizing various aspects of regulation--coupled perhaps with government grants to encourage vigorous action at the state and local levels.

F. More Effective Government-Industry Control of Technology Programs

Government-sponsored control technology research and development programs must be better designed to address the total pollution problem in a given industry, the secondary environmental impact, and the broad applicability to related industrial sectors. These programs would allow the Agency and industry to address pollution problems more economically--for example, by avoiding the regulation of just one pollutant at a time.

(Regulations currently proposed by the glass industry address particulates only and do not consider SO_x, NO_x, arsenic, and fluorides.) The development of more economical technologies that allow a "once through" regulatory process would encourage industry to work more closely with the EPA and to allocate more of its expertise and resources to environmental control programs.

In addition to these broader considerations, the Agency should publicize within the private sector its desire to find the best possible approaches to solving specific problem areas. Grants and contracts that invite both industry and universities to participate would elicit the best expertise and the most thoughtful approaches available to solve the problems. Besides providing financial incentive, the EPA would improve its technical credibility and increase industry's willingness to participate in the work of developing more efficient and cost-effective technologies.

The Committee recommends that incentives for industrial participation in research projects be increased. For example, the merits and drawbacks of letting the developers of new technology retain the rights to market their technological innovations might be considered.

G. The Contract and Grant Specifications of Federal Agencies

All federal agencies, but particularly those (like the Department of Defense, the General Services Administration, the Department of Housing and Urban Development, and the Department of Transportation) that purchase directly or control the purchase of manufactured goods, can provide industry with a major incentive to use processes that pollute less and to develop products with the least possible environmental impact. Thorough examinations of the contract and grant specifications in those agencies, that identify where the specifications can be written to favor government or government-subsidized purchases of the most environmentally safe products or products derived from the most environmentally safe processes, would help accomplish this objective. For example, the federal government could stop buying cadmium-plated products, except where the special properties from cadmium plating are absolutely necessary. This practice would reduce cadmium plating, which presents a serious environmental and occupational pollution problem.

For a second example, the government could stop purchasing furniture coated with solvent-based paints, or pay a "bonus" for furniture coated with water-based paints. This practice would encourage the furniture industry to try to convert to water-based paints, thereby reducing or eliminating a serious environmental, health, and occupational hazard. Similarly, other specifications might address such other coating operations as metal finishing in the automotive industry, requiring it to use solventless or high-solids coating operations.

In a related manner, the federal government could give special recognition to low polluting products and processes through the Federal Register, in advertising campaigns, or in other ways that bestow recognition on environmentally safe products and processes.

A research program should thoroughly identify candidate processes and products and examine the potential economic impact and the benefits and drawbacks of such federal action.

H. Federal Purchasing Practices

When the federal government purchases items from private industry, it can exercise powerful influence over that industry. To encourage pollution abatement, the government could stipulate that it will purchase only items produced in a non-polluting manner. For instance, some residents had been unsuccessfully trying for quite a while to have a small asphalt producing plant control its effluents. Finally, the state decided to buy asphalt only from a company that met federal emissions standards. The offending plant quickly complied with these standards.

This example suggests a positive incentive to clean up the environment. In instances like this the government can, of course, set up whatever standards it considers desirable without having to justify them in court. Moreover, if a company must improve a process to meet the requirements of one customer, it will often improve the process for everything it produces. (This general improvement could even become a requirement of the purchaser.) These tactics might, of course, be extended to include items bought on government contracts or from companies already awarded government contracts. They could also encourage intergovernmental cooperation among all federal agencies. Moreover, state and local governments might be encouraged to adhere to these policies.

I. EPA Control Technology Research

A number of small industries are unable to do research on their own--the tanning, dry cleaning, electroplating, printing, and engraving industries, for example. The EPA should work with these industries to help them reduce potentially damaging waste discharges. The incentives for these programs would be a more healthful environment for employees and better neighborhood public relations. The role of the EPA might be to help these industries find economical ways to reduce pollution and to meet established standards. The EPA could fund and conduct the research, then use the companies' facilities to test the suggested solutions.

A second approach might be to allow the EPA to award a tax rebate to those small industries that produce less "pollution per pound" than the industry average for the product. The size of the rebate might be based on the size of the pollution reduction. This plan might encourage small industries to look for ways to reduce their own pollution and would contribute substantially to the overall research effort.

J. Treatment of the Air

Such resources as drinking water are routinely purified by such treatments as the addition of chlorine. One resource not so treated is the air. All pollution control involves the reduction or elimination of emissions in the atmosphere. In principle, more effective or less expensive air pollution control might be possible by treatment; therefore, air treatment methods should be investigated.

Indoor air is sometimes treated by "odor masking" techniques. These techniques could be adapted to pollutant removal--for example, recirculating air through filters. Likewise, polluted air from outside could be treated before circulating indoors.

Some air pollutants form as the result of chemical reactions in the air. For example, sulfuric acid forms from the oxidation of sulfur dioxide, or photochemical oxidants form from the oxidation of nitric oxide and hydrocarbons. It has been suggested that air could be chemically treated to prevent the formation of these secondary pollutants (Schaal, Partymiller, & Heicklen, 1978). Such methods might, in some situations, be relatively easy and inexpensive to implement.

K. Grants to Communities

To bring public pressure to bear on local industry to reduce pollutant emissions, the Committee suggests that the federal government investigate the possibilities of offering specific or open-ended grants to the community or county in which the industry is located. These grants could underwrite new recreational areas, health facilities, or educational programs, depending on the needs of the community. But the government could predicate the funds on local compliance with pollution standards.

L. Federal Guarantees for Improved Product Development and Commercialization

One potentially fruitful incentive would be to allow the federal government to guarantee long-term purchases of a minimum number of items that pollute less than the item they replace, or of pollution abatement devices per se.

For instance, the EPA or the Department of Energy might institute a contest to find a new residential wood stove that is inexpensive, conserves energy, and produces a minimal amount of pollution. The winner would receive a contract to produce 1,000 stoves a year for ten years at, say, $500 a stove. This contract would provide an adequate amount of funds for the entrepreneur to obtain the loans necessary to commercialize the product and (ideally) to ensure its introduction into the marketplace. The government might donate the stoves (for example) to Community Action Agencies for installation in poor people's homes.

M. Jointly Developed, Implemented, and Sponsored Control Technology Research and Development Programs

The EPA could commit itself to developing control technology research and development programs jointly with the affected industry in such specific, but major, problem areas as the organic chemical industry. This approach would incorporate the cooperation of the industry and thereby encourage the industry to seek the best, most economical, solutions and, thereafter, to apply the newly developed technologies. Establishing high-level industry-government standing committees within the affected areas would be a key mechanism for successfully implementing such an approach. And, if successful, the approach would suggest more realistic regulations. A major objective of such an approach would be to enlist industrial expertise and resources against pollution problems.

N. Environmental-Economic Analysis of the Secondary Impact of Regulations

A newly promulgated regulation often produces resistance and foot dragging. It may also incur challenges that the problem has merely been transferred to a different media, or fears of major socioeconomic impact to come. We call these reactions to the "secondary aspects of regulation." Whether the agency is seen as an adversary or a partner depends heavily on these secondary aspects. The Agency must do more to consider all the effects its regulations will have before it promulgates them. If the EPA is considered a partner, not an adversary, it will naturally win more cooperation. More cooperation may well mean better pollution abatement. Moreover, if industries and citizens become involved in the study of these secondary effects, everyone will feel that he has influenced the regulation and that the regulators understand the individual problems.

Another area that concerns the Committee is the absence of disinterested review of the EPA's policy analyses. The EPA conducts extensive research on the impact of its policy, but the Agency retains primary control over the selection of the assumptions used in its analyses. The EPA should enlist the aid of a broader spectrum of observers able to appraise the validity of these policy analyses.

O. Environmental and Economic Analysis of the Impact of Regulations--A Preferred Regulatory Strategy

The Office of Research and Development could evaluate the environmental and economic impact of the current regulatory approaches to specific segments of industry to identify a preferred regulatory approach to air and water pollution and solid waste control. This holistic approach would encourage industry to participate and cooperate because it would lead to a lessened economic impact and avoid piece-meal approaches that (in too many cases) circumvent the more serious problems of an industry anyway. This approach would also keep industry informed about the EPA's intentions and would allow the EPA's Office of Research and Development to focus its attention on the most serious problems. The industries' participation would also help ameliorate the adversary relationship between the government as regulator and industry.

P. Incentives for the EPA

The EPA serves primarily as a regulating agency. Therefore, its primary interest is to "regulate" pollution problems or to search for new problems to be regulated. Just as the medical profession would disappear if everyone were well, so it has been alleged that the EPA has little to gain from finding technological solutions to pollution problems. The Committee recommends, therefore, that some mechanism be found to encourage the Agency to find technical solutions to the problems in its domain. These mechanisms could consist of awards or promotions to those within EPA who institute successful technical rather than regulatory approaches to pollution problems.

Another approach might be to encourage new pollution control and reduction ideas and innovations. The Committee expressed concern that the EPA may have become overly committed to specific approaches. It might be desirable to encourage the Agency to consider innovative approaches. Perhaps the EPA could establish an office to promote novel or high-risk approaches.

Q. Tax Incentives for Individuals

Although the federal government has made important strides in providing tax incentives for individuals who incorporate fuel conservation measures into their homes or install solar energy heating and cooling systems, the Agency could investigate additional incentives to encourage these measures among localities and homeowners. For example, if a person improves the value of a house by installing solar heating, the local tax evaluation might perhaps be held in place. Or, the federal government might offer appropriate property tax relief to communities that initiate fuel conservation programs.

III. Recommendations

Although the Committee on Incentives and Framework for Control did not agree upon specific recommendations for EPA research, the following represents a synopsis of the major points discussed during their two days in session:

(1) Studies should be made of imaginative environmental programs in other countries to determine the relative practical merits of financial incentives compared to the various regulatory strategies currently employed.

(2) Research efforts utilizing animal models and epidemiological studies should be directed toward more precisely defining the effects of toxic substances on high-risk groups in order to obtain more accurate data upon which to base regulatory decisions.

(3) Research should be carried out to determine the best division of responsibility for enforcement programs among federal, state, and local governments.

(4) A continuing program of applied social-scientific research on the monetary benefits of control of all forms of pollution should be instituted.

(5) Research should be carried out on the reasons that catalytic converters on automobile exhausts do not function properly. For example, are they technically inadequate? Are they being tampered with by the owners? Are they rendered inefficient by the use of leaded gasoline?

(6) Where possible and practical, more research should be done on the effects regulations will have before they are promulgated. Industry and individuals, in addition to EPA employees, should be involved in this activity.

(7) Funds should be committed to reward those who have developed innovative approaches to pollution control and reduction.

(8) Studies should be made of alternative strategies for implementing the existing goals in auto emission control.

(9) Research should be undertaken in cooperation with small industries which do not have the capability of doing research on their own (for example, tanning, dry cleaning, and electroplating industries) to develop means for

reducing potentially damaging emissions.

(10) Research should be carried out to address the total pollution problem of a given industry segment, including secondary environmental impact, and its broad applicability to related industrial sectors.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

Source Characterization

April 23 and 24, 1979

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SOURCE CHARACTERIZATION

I. Introduction

The United States Environmental Protection Agency and its predecessors have traditionally considered source characterization narrowly, concentrating efforts on one or relatively few individual pollutants (e.g., SO_2, BOD, etc.) from large, easily identifiable sources. But the enactment of legislation that reflects the growing concern over the harmful effects of a multiplicity of pollutants or chemical entities requires a redefinition of environmental control strategy. Such a redefinition must take into consideration the nature of both the source and its discharges to the environment.

These discharges must be quantified according to their chemical, physical, and biological properties. For industrial sources, quantification also would include such process elements as raw materials and products. The great increase in the number of pollutants of concern requires a concomitantly effective strategy for characterizing sources and a methodology for selecting the most critical sources for immediate characterization.

II. Specific Recommendations

The large numbers of pollutants to be handled in the coming years compels the Committee to make the following recommendations:

(1) We need a strategy for selecting those sources that could potentially cause severe environmental insults. Assessing all of the discharge streams associated with polluting activity in the U.S. would be impractical--the organic chemical industries alone produce thousands of individual discharge streams.

(2) We need a comprehensive definition of the parameters to be included

in source characterization.

(3) We need a logical system for selecting and classifying the most critical pollution sources. This classification system might encompass

a. the extraction and processing of non-renewable resources;

b. the production and processing of renewable resources;

c. the formulation and fabrication of consumer products; and

d. the use and disposal of consumer products.

Each of these activities, except d, takes place in logically definable industries which could be used as sub-sets for more detailed investigation.

(4) We need a statistically valid methodology for selecting specific sites for characterization within selected industrial categories.

(5) We need a master plan for characterizing sources. This plan should include process descriptions, raw materials, products, discharges, streams, sampling methodology, and analytical methodology.

III. Discussion

The deliberations of the Source Characterization Committee suggest that at least three segments of man's activities will rank high in almost any logical source selection methodology. Of the groups of industries whose discharges have the highest potential health hazard, the Committee recommends that researchers employ the following priority:

a. the production and use of organic chemicals;

b. the production and use of metals; and

c. fossil-fuel-fired small boilers.

Discussions of these three segments and the justification for the priority suggested appear in the next paragraphs.

A. The Production and Use of Organic Chemicals

The past and present pollution control practices of the organic chemical industries produce serious environmental impact. The environmental impacts of chemicals dumps, episodes of emitting into the air such chemicals as dioxins, and problems associated with the use of pesticides and herbicides illustrate the need for better understanding of the character of the organic chemical industries so that such environmental insults as these can be avoided. Past work attempted to define the industry-process-discharge relationships in the chemical industries. This work should be expanded, as necessary, to provide a basis for new EPA programs designed to control serious chemical contamination to the environment.

B. The Production and Use of Metals

Contamination of the environment by potentially toxic metal compounds appears to be a significant and growing problem. Specifically, volatile metal releases associated with production of such metals as arsenic, cadmium, and lead have been an increasing source of concern. Also, discharges of aqueous wastes from processes that use metals (metal finishing and the production of chemicals, for example) have been associated with problems in municipal waste treatment, plant contamination, stream pollution, and groundwater contamination. Work aimed at defining the industry-process-discharge relationships in both metal production and in those industries that consume metals should be expanded.

C. Fossil-Fuel-Fired Small Boilers

While combustion in large boilers has been the subject of environmental concern for many years, the potential for serious environmental impacts attributable to combustion in small commercial, institutional, and industrial boilers has only recently been recognized. Boilers smaller than those presently subjected to new source performance standards (NSPS) consume about half the boiler fuel used annually, and they burn more oil than utility boilers. Moreover, coal consumption in small boilers is expected to increase as other fuels become more expensive or unavailable. Furthermore, small oil-burning boilers are now suspected health hazards because they often discharge such pollutants as metal compounds, sulfates, and unburned hydrocarbons from low-level stacks in populated areas. The current work aimed at defining and controlling discharges from small boilers should be expanded.

IV. General Recommendations

In light of this discussion, the Committee recommends that the EPA undertake the following research initiatives:

(6) The EPA should develop a general strategy for estimating the environmental impacts of industrial activity and for determining the urgency for studying the various effects.

(7) To test and refine this strategy, the EPA should study the following areas first and in this order:

a. the production and use of organic chemicals,

b. the production and use of metals, and

c. fossil-fuel-fired small boilers.

COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

Separation and Treatment Technology

April 26 and 27, 1979

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SEPARATION AND TREATMENT TECHNOLOGY

I. Introduction

Traditionally, the development and assessment of control technology in a given media is based on the removal of a few select materials. But there is a growing awareness of such gross-media and multi-media impact as atmospheric deposition of nutrients into lakes and the precipitation of acids that affect water quality. In addition, hydrocarbon emissions from wastewater treatment operations, toxicants from incinerators, and possibily N_2O emitted as a result of the soil's denitrification of the nitrogen in fertilizer or sludge, illustrate the impact wastewater and sludge management practices can have on air quality. Research efforts associated with the characterization of emission sources and the control technology evaluations in a given media should be expanded to include pollutant parameters of interest to programs focusing on other media.

II. Recommendations

A. Develop Control Management Practice

In both air and water pollution, the wide distribution of an emission implies a potential for a large impact difficult to abate at any one emission source. Urban and agricultural run-off provide two examples of such water pollution problems. Particulate and gaseous emissions from many small combustion sources illustrate a typical air pollution problem. The abatement of these sources may be accomplished by developing control management practices and establishing general approaches for controlling disparate sources.

The quantity of pollutants generated by any single domestic furnace, wood-burning stove, boiler, or water heater may be small; but the aggregate of these emissions over a metropolitan area can comprise a substantial portion of the total pollutant emissions in the area.

Though it may not be feasible to use control equipment to reduce these emissions, it may be possible to design domestic fuel combustion equipment so as to reduce the generation of such pollutants as CO, HC, or NO_x.

(1) Accordingly, the Committee recommends that the Environmental Protection Agency (EPA) establish the feasibility of redesigning domestic combustion equipment to reduce the quantities of pollutants generated.

In addition, the Committee notes that the problems associated with the release of such materials as plasticizers into the indoor air are aggravated by tight weatherstripping and other procedures used to reduce exchange of indoor and outdoor air for energy conservation.

B. Hazardous Waste Control

The Committee finds a need for research that develops the technology needed for hazardous waste control and that develops the criteria defining adequate control methods. Several types of technologies may be applicable for hazardous waste control. These include

(a) Recycling or reusing the waste products;

(b) Chemical destruction;

(c) Filtration and other separation; and

(d) Chemical alteration.

In general, the nature of the chemical structure of those organic materials leading to toxicity, hence the degree of alteration of chemical structure required to destroy those materials, is not fully understood. Also, where catalytic metals are present, some incineration processes may form toxic materials.

One of the more promising means of hazardous waste control is incineration in a rotary kiln analogous to a cement kiln. The engineering expertise needed to predict the performance and scale of the laboratory data is, however, not always available. Further research in this area would minimize the number of pilot plant studies needed relative to the large number of hazardous waste sources. For example, it is often difficult to distinguish the chemical degradation products from a hazardous waste, given knowledge of the temperature-time history of an incinerator.

(2) Thus, the Committee recommends mobile or on-site methods of removal, detoxification, or containment to remedy the potential environmental and health consequences associated with improper disposal of hazardous wastes over the land. Model facilities able to deal comprehensively with hazardous wastes must be developed and built. Also, better methods of containing or treating hazardous waste spills on land and water must be developed.

C. Flue Gas Desulfurization

The current commercial and pilot-scale processes for scrubbing sulfur dioxide from the flue gas from coal power plants do not provide technically and economically attractive solutions to operational scaling and waste disposal problems. The Committee sees a need for an improved understanding of the fundamental thermodynamics and kinetic mechanisms involved in the scrubbing processes. Some of the design and correlation techniques are empirical and are based on data derived from a limited range of operational parameters. They are not necessarily extrapolated readily to different coals, neutralizing agent sources, or the oxidative state of the scrubbing fluid. For example, in the limestone slurry scrubbing of flue gas, the rate controlling mechanisms for sulfur dioxide sorption and the dissolution rate of limestone apparently cannot be reconciled.

A better understanding of the thermodynamics of the aqueous salt systems encountered in flue gas desulfurization should lead to better control of scaling and to improved residue characteristics. There is an obvious need for research into sludge dewatering as a means of reducing the waste disposal problem posed by flue gas desulfurization.

Perhaps the most efficient methods of flue gas desulfurization involve processes that produce elemental sulfur as a solid byproduct. We need additional pilot and commercial-scale evaluations of these processes, especially from the standpoint of economics. In addition, any novel conceptual ideas that promise to reduce the problems associated with solid waste disposal should be pursued.

(3) Thus, the EPA should work to improve our understanding of the gas desulfurization process (using thermodynamic and kinetic modeling) with special emphasis on those systems with promising residual disposal characteristics and economics.

(4) The EPA should assess options for sludge disposal.

D. Sludge and Refuse Disposal by the Thermal Conversion Processes

Recent studies of sludge incinerators indicate that lead and cadmium in the feed stock may be concentrated as much as 50-fold in the particulate emissions. Most of the cadmium and lead content is associated with particles smaller than 10 microns in diameter which are not effectively removed by low intensity scrubbers. A modeling of the lead emission rate, under assumed worst meteorological conditions, predicts violations of the ambient air quality lead standard. Annual average calculations, however, show emissions rates for lead at only 3 percent of the ambient standard. No standard for cadmium has been established.

(5) The Committee recommends, therefore, additional emissions characterization and air pollution control technology evaluation studies that focus on different types of incinerators and other thermal conversion processes.

E. Organic Sludges

The occurrence and fate of heavy metals in municipal and other sludges is currently being evaluated. We know little, however, about the toxic organic materials in these sludges and their effect on crops, groundwater, and metal mobility. We also know little about the possible adverse transformations that occur when these materials are subjected to such stabilization processes as super chlorination.

(6) Thus, we recommend the initiation of a research effort to characterize and evaluate the fate and effect of the organic portion of sludges.

F. Radioactive Emissions from Nuclear Power Plants During Operational Mishaps

The recent incident at the Metropolitan Edison nuclear power plant on Three Mile Island has shown that emergency shutdown systems cannot be counted on to prevent significant contamination of the air and water. During the Three Mile Island incident, large volumes of uncontrollable steam and gases passed into the atmosphere, and a large volume of water flowed into the Susquehanna River. These releases contained significant quantities of radioactive gases, liquids, and particulates. The radioactive species include tritium, tritiated water, krypton, xenon, and iodine. Fission products from failed fuel elements may also have escaped.

Fortunately the amount of radiation released was not catastrophic. But considering that the primary cooling water alone can contain up to 10^5 curies of radioactive species, the possibility of future catastrophic releases from pressurized water and other types of nuclear reactors remains very real. Once the radioactive species become dispersed in the ecosystem, they are impossible to recover and isolate, and they impose an extreme environmental hazard.

(7) EPA, in cooperation with the Nuclear Regulatory Commission, should investigate the technical and economic feasibility of improved site containment, concentration, and disposal of radioactive emissions from those nuclear power plants that experience operational mishaps.

G. Water Pollution and Toxics Control

Most of the exchange treatment-separation technologies used in water treatment have been designed to meet numerous standards. But many waters contain particularly noxious components at levels below 1 mg/l whose impact is inadequately understood or documented. Furthermore, the removal technologies for components at these levels have received only limited consideration.

(8) Further research should, therefore, focus on technologies designed to remove noxious components in concentrations below so many parts per million (and especially at or below levels of parts per billion).

Specific examples could involve heavy metals like cadmium, organics like the polynuclear aromatics, or carcinogens, but they would incorporate components thought to have either acute or chronic impact.

(9) The Committee recommends especially basic research into the treatability of compounds and classes of compounds that considers structural correlations, if possible, as well as alternative adsorbants.

The related technologies that remove trace components from air emissions also need more extensive study, even though they may be more advanced than the technologies designed for water.

H. Municipal and Industrial Wastewater

Some municipal wastewater is reused in California and Long Island in areas that take advantage of groundwater recharging. Direct potable wastewater reuse is being proposed for evaluation in Denver (Denver Research Institute, 1979).

(10) The Committee recommends a program that monitors the current practices and an evaluation of the Denver project, including a test of the health effects. The goal of this effort should be standards for effluents treated for reuse.

Wastewater to be reused by industry might be subdivided into cooling water and water to be used directly in the industrial process.

Most cooling water is already recirculated through cooling towers. A significant portion of "process" water is, however, not recirculated. Some of this water cannot be reused because it is directly consumed in the process, but a potential exists for the reuse of a good deal of wastewater.

(11) The EPA should, therefore, develop criteria for this water reuse. These criteria might include the concentrations of COD, BOD, and TSS removal; and the acceptable pH range. Such criteria would in many cases be specific to the use. Secondly, the EPA should encourage research to develop the technology to treat water for reuse so that it meets these criteria.

I. Biological Process Development

The most prevalent form of municipal wastewater treatment is biological, primarily the activated sludge process. Significant savings may be possible through the development of high-rate systems with high concentrations of reactive solids and external oxygen dissolution. Operating economies and reliability may result from an improved understanding of process control alternatives, of the effects of influent toxics on performance, and of multistaged operations designed to achieve the biological removal of phosphorus and nitrogen.

(12) The Committee recommends a program of pilot testing and full-scale evaluations of these systems.

J. Dissolved Solids

Many streams occurring naturally as surface run-off flows reach the surface from groundwater sources. These streams may contain significant levels of dissolved solids (as measured directly or as indicated by conductivity determinations). Most water of this kind complies with existing quality regulations for various utilization purposes, with these exceptions: oceans, certain lakes, brine deposits, and water containing specific toxic trace components. These waters may be amenable to various treatment procedures that remove suspended solids, control pH, remove organics and other noxious components, or even add oxygen. But the treated effluent may still contain substantial kinds of dissolved solids. The existing knowledge of the long-range effects on biota of using these waters is limited--as is cost-effective technology for reducing or removing these soluble components. Most of the current removal technology follows distillation or desalination procedures and involves such concepts as distillation, freezing, extraction, ion exchange, and reverse osmosis.

The broad application of such technology and the health impact on biota from using this water has been limited to regions (typically acid) where other water sources are sparse or nonexistent. Under those conditions the regions have used the technologies just discussed, and the high costs have been justified.

(13) Accordingly, the Committee recommends further research designed to produce cost-effective control technologies for reducing or removing dissolved solids at major point sources of effluent discharges or at collection points.

Specific examples in which such technologies would be useful include homes associated with oil-gas deposits; coal mine drainage; and mineralized groundwater associated with other mineral deposits, especially sulfide and carbonate ores. In addition, numerous industrial wastewater streams, like plating and etching solutions and pickle liquors, contribute to the problem.

K. Control Technology for Carcinogenic Air Pollutants

Gaseous hydrocarbons and particulate emissions can include known carcinogens in trace quantities. Other emissions may be found to be carcinogenic in biological tests. Control of these emissions presents special problems because of the low concentration of the carcinogen or because the nature and concentration of the biologically active fraction may be unknown. Additional control problems arise if the emission does not come from a ducted stationary source.

(14) Control technology development in this area should include the assessment, testing, and evaluation of conventional control approaches and research into identification and evaluation of new control approaches.

L. Control Technology for Fugitive Emissions

(15) The EPA should attempt to develop efficient methods for controlling fugitive emissions. Fugitive emissions are nonducted and cannot be controlled by conventional means. Examples of fugitive emissions include hydrocarbon leaks from valves and fixings, particulates from steel plant operations, leaks from tanks, and reentrained dusts from roads and storage piles.

A knowledge of fugitive emissions would be particularly valuable in the performance of offset calculations. Additionally, the long-term effectiveness of maintenance programs in reducing fugitive emissions has not been satisfactorily ascertained. Some of these emissions, such as those in selected steel processing steps, cannot be collected economically.

(16) The Agency should encourage the development of the technology to control these emissions and gather information on the effectiveness of various control strategies.

M. Design and Modeling of Particulate Control Equipment

Controlling air pollutants at their sources often depends upon the proper design and operation of pollution control equipment. Inadequate equipment performance can permit the escape of air pollutants that adversely affect public health. Thus, the procedures used to design this equipment must be well established, and the equipment must meet design specifications.

The design procedures are not yet well established, and new control equipment is too often designed by analogy to successful past experience, rather than guided by a firm grasp of the fundamentals that affect performance. An increased awareness of the adverse effects small particles have on general health and visibility could encourage the use of efficient control devices in processes to which they have not previously been applied. Without a clear basic knowledge of how these collectors work, one cannot design collectors that perform reliably.

Although we can apply some information of this type to electrostatic precipitators and scrubbers, we have little information that applies to fabric filters, the most efficient collectors, and the collectors to which processes turn as emission regulations tighten.

(17) Accordingly, the Committee recommends that studies be made to determine how, basically, particles are collected and retained by particle control devices, especially those that collect small particles efficiently. Efforts should also be made to develop design and performance models that correlate collector performance with the fundamental ways in which a collector captures and retains particles.

Adequate models simply cannot be developed until the fundamentals that affect collector performance are identified and adequately described. Recent studies have shown that existing performance models, which consider only the methods by which particles are collected, are inadequate when applied to collectors operated under high efficiency conditions. Much of the dust that penetrates high efficiency filters and precipitators does so by a fault process like seepage, or by penetrating through pinholes (filters), or by gas "sneaking" past collection plates (precipitators). The knowledge and models adequate to characterize collector performance under less extreme efficiency requirements become inadequate when applied to high efficiency conditions.

(18) Accordingly, the Committee recommends that the EPA encourage an understanding of control device performance and characteristics under high efficiency conditions so that models adequate to describe high efficiency performance can be developed. A better understanding of particle separation

methods that result from implementing these recommendations should foster the development of control techniques that operate with higher efficiency and at a lower cost.

(19) To promote development of these techniques, the Committee recommends that studies be made to apply new technology to the development of new pollutant collective devices.

N. Processes for Simultaneous Removal of SO_x and Particulates

Evidence is mounting that particulate sulfates, derived in part from SO_x emissions at fossil-fueled power plants and transported over long distances, have an adverse effect on the health of large populations. Removal of the SO_x precursors at the combustion source is one approach to reducing sulfate and SO_x concentrations. Currently, most SO_x removal processes involve the wet scrubbing of gases with lime, limestone, or some other basic material. The effective, reliable operation of these processes requires careful control and maintenance. Moreover, these processes produce large amounts of liquid waste that are difficult to treat.

Dry processes for SO_x absorption and adsorption using a spray-dried slurry of a basic solution reduce SO_x emissions reasonably well. This spray-dried slurry (aerosol) is removed from the gas stream with a high efficiency fabric filter that simultaneously removes SO_x and particulate matter. The pollutants removed are dry and do not raise the sludge disposal problems associated with liquid processes.

This process does not remove SO_x as efficiently as liquid scrubbing does. The cost of the process, moreover, appears to depend in part upon the availability of the dry sorbant. But if these difficulties can be overcome, the spray-dried sorbant process holds promise; it produces no liquid wastes and it simultaneously removes particles quite efficiently.

(20) Accordingly, the Committee recommends that studies be made to

determine how the spray-dried sorbant process for removal of SO_x from flue gas can be made more efficient and economical.

O. SO_x/NO_x Control Technology

The Committee believes that the EPA should continue to conduct and fund research to develop a process capable of removing both SO_x and NO_x from gas streams (primarily power plant stack gases).

Some 100 processes have been proposed for the removal of SO_x from (primarily) stack gases, and a smaller but substantial number has been proposed for the removal of NO_x. Several SO_x removal processes have been developed commercially--notably lime, limestone, Wellman Lord, dual alkali, and magnesium oxide. These processes have limited, if any, potential for NO_x removal. Some NO_x removal processes are available, including reduction with ammonia, but their state of commercial development is less advanced than that of the SO_x processes.

(21) Accordingly, the Committee sees a need for a control process suitable for the simultaneous removal at high efficiencies of both SO_x and NO_x.

(22) The Committee also recommends the development of economic control technology for such smaller emission sources as residential furnaces and small boilers like those in chemical process plants.

P. Control of Pollutants from Indoor Sources

Most people spend most of their time indoors; and they spend much of this time at home. Many activities carried out routinely at home can generate substantial quantities of such pollutants as CO or NO_x. For example, recent evidence suggests that children who live in houses with unvented gas stoves evince reduced lung function as measured by standard physiological tests. We have as yet paid little attention to designing such appliances as stoves and space heaters to reduce their pollutant generation rates.

(23) Accordingly, the Committee recommends that studies be made to determine the means by which pollutants generated indoors can be reduced.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
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Process Change-Product Substitution

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PROCESS CHANGE-PRODUCT SUBSTITUTION

I. Introduction

Many environmental pollution problems could be alleviated if suitable process changes were effected to inhibit pollutant formation, or if hazardous or toxic products, by-products or intermediates could adequately be substituted for. In many cases, such changes or substitutions could eliminate waste treatment by making effluents environmentally acceptable. Accordingly, the discussion that follows explicitly excludes the modification of waste treatment processes and ultimate disposal technology.

A. Definitions and the Scope of the Discussion

In the paragraphs that follow, process change implies process alterations that reduce environmental pollution attributable to toxic or noxious substances while maintaining product quality and production levels. Product substitution implies the replacement of one product with an alternate product acceptable to the environment and more conducive to the health of individuals.

Research needs in process change and product substitution will be considered in the context of two broad processing areas: (1) chemical processes, and (2) combustion processes.

Chemical processes include the manufacture and use of industrial chemicals and may be classified as follows: processes for primary chemicals; such processes for secondary chemicals as fibers, dyes, pharmaceuticals, plastics, resins, and pesticides; such primary non-chemical processes as mining, refining, and smelting; such compounding products as detergents, surface coatings, adhesives, and cosmetics; such processes for fabricated products as metal works, textiles, and plastics; and such trade and service processes as dry cleaning, transportation, restaurants, and hospitals.

Combustion processes include such stationary sources of combustion as utility, industrial, commercial, and residential boilers; residential furnaces and hot water heaters; industrial process equipment (like kilns, ovens, dryers, and process furnaces); stationary engines (like gas turbines and internal combustion engines); and incineration. The fuels utilized in stationary combustion sources include process and natural gas, oil, coal, coal-derived fuels, alcohols, shale oil, industrial process wastes, municipal wastes, and combinations of these fuels. Mobile combustion sources include automobiles, trucks, airplanes, trains, and ships. Fuels utilized mobile combustion sources include gasoline, diesel oil, alcohols, and jet fuel.

For convenience of discussion, those products and processes involved in the preparation and use of fuels for any purpose whatsoever are considered together. All other chemical products and processes, organic and inorganic, are grouped as a second category in this text. Fuels are characterized by a relatively small number of hazardous products at a high volume which, therefore, present possibilities of large-scale pollution. All other chemicals are used in relatively low volumes (the annual production of our most common polymer, polyethylene, is equivalent in tonnage to only a few days use of gasoline). But there exists a multitude of these compounds--scores of thousands. The amount of pollution or health hazards these chemicals produce is much lower than for fuels, but the probability of their forming undesirable or toxic compounds and the probability of someone encountering these compounds are much higher. Consider the lasting and tragic effects of the release of small amounts of PBB or dioxin, for example.

A large national effort is already directed toward fuels research and development, but the current environmental impact of conventional fuels and combustion processes and the potential environmental impact of new fuels and combustion processes are so great that this general area deserves continued emphasis. As for the other chemical products, their vast numbers will, of themselves, generate research needs. All the undesirable properties and effects of so many different compounds cannot realistically be identified, in spite of the diligence of the agencies now monitoring their production and use. To complicate the situation, no one can foresee the uses individuals and organizations will find for these materials, or all the manufacturing processes that may generate hazardous intermediate or waste products.

The Committee sees a need for research to find substitute products and to develop alternate or modified processes. The problem for the EPA in administering its original assignment, as well as the Toxic Substances Control Act and the Resource Conservation and Recovery Act, is to maintain a balance between what will be accomplished by normal competitive enterprise on the one hand, and on the other hand what will be accomplished only if the EPA intervenes to stimulate work.

With its limited resources, the EPA must balance what various advocates say needs to be done against what can be done, and it must also balance the need to meet short-term (or crisis) demands against long-term research goals. The recommendations and discussion the Committee offers in the following paragraphs were written with these imperatives in mind.

II. Recommendations

A. Specific Needs in Combustion Processes

Specific research needs in the combustion process area and their rationale appear below according to funding priorities the Committee considers appropriate. The Committee based these priorities primarily on perceived probability of success and on greatest potential for effecting improved environmental quality. In each case, the effect of the process modification or product substitution should be determined not only for emissions, but also for process performance and energy utilization. The pollutants of concern for combustion processes include oxides of nitrogen, oxides of sulfur, hydrocarbons, carbon monoxide, particulates, trace species including trace metals, polycyclic organic matter, and other organics.

In order to be able to adequately assess the emissions from combustion sources and to be able to assess their overall effect on the environment, it will be necessary to continually update environmental assessments of these processes. It will be especially important to evaluate the effect of process modifications and product substitutions for combustion sources. To be comprehensive such evaluations should include carefully planned chemical and biological sampling and analysis. Appropriate data banks should be maintained by the EPA in order to assure readily accessible retrieval of such information.

(1) Improved Burner-Furnace Design

Many major air pollutants are formed during the combustion process. For those pollutants that can be controlled by burner-combustor modification, this approach is more cost-effective than such alternate methods as flue/exhaust gas treatment.

Accordingly, the Committee recommends that increased emphasis be placed on the control of emissions through improved burner-combustor design. This approach is applicable to a wide range of stationary and mobile combustion systems including boilers, furnaces, industrial process equipment, gas turbines, and internal combustion engines.

(2) The Development of Advanced Combustion Technology

Advanced combustion technologies can provide more efficient and environmentally acceptable energy generation from fossil fuels than conventional combustion methods.

Accordingly, the Committee advocates the continued development of such advanced combustion processes as fluidized bed combustion, catalytic combustion, and low emission burners. Other alternatives with potential for significantly reducing emissions and enhancing efficiency should be supported whenever they present themselves.

(3) Improved Dynamic Process Control

Many process modifications have been developed for use during steady state operation. During load swings or upset conditions, the performance of modified processes may be seriously impaired (for example, the use of staged combustion combined with low-excess air firing), leading to large emissions and loss of efficiency.

Accordingly, the Committee recommends that improved dynamic process control systems be developed so that the full potential of process modifications can be realized under transient as well as steady state conditions.

(4) Emissions Control in Coal Conversion Technologies

Many analysts project a greater utilization of coal, and such new coal conversion technologies as coal gasification, coal liquification, and coal refinement by solvent extraction obviously threaten to increase multi-media emissions.

Accordingly, the Committee recommends that environmental assessment be initiated early in the development of coal conversion technology so that process modifications to control pollution may be integrated into the evolving design concepts.

(5) The Utilization of Coal-Derived Fuels, Shale Oil, Waste Oil and Alcohols

These alternate fuels are increasingly likely to find utility, industrial, residential, and mobile applications, and they have potential for increased emissions (for example, NO_x derived from fuel-bound nitrogen).

Accordingly, the Committee suggests that studies will be needed to determine the emission characteristics of these fuels and their susceptibility to emission reduction and efficiency enhancement through combustion and other process modifications.

(6) New Combustion Areas for Process Modifications

To date, process modification to effect emission control has been applied mainly to utility and industrial boilers and to internal combustion engines. Cost effectiveness recommends the application of this approach in other combustion systems.

Accordingly, the Committee recommends that the use of process modification be considered for controlling emissions from such sources as industrial process equipment, residential and commercial wood and coal-fired systems, gas turbine combusters, diesel engines, and coal-fired stoker boilers.

(7) The Mechanism of Fuel Nitrogen Conversion

Oxides of nitrogen (NO_x) are pollutants that can be effectively controlled by process modification because they can be reduced, in situ, to harmless nitrogen. The projected increase in the use of coal and coal-derived fuels that contain large fractions of fuel-bound nitrogen relative to other fuels indicates the need for combustion modifications to suppress conversion of fuel-bound nitrogen to NO_x.

Accordingly, the Committee advocates fundamental studies to determine the mechanism and chemical kinetics of NO_x formation from fuel-bound nitrogen. This knowledge should subsequently be applied to modification strategies for NO_x control.

(8) Fundamental Research

Large funding allocations made for pilot studies and demonstrations are often based on only a limited understanding of the underlying chemistry and physics. Therefore, we need fundamental research to support development work and to increase the possibility of significant discoveries.

Accordingly, the Committee recommends that more emphasis should be placed on fundamental research related to combustion and the associated formation of pollutants.

(9) Alternatives to the Gasoline Engine for Mobile Sources

The demand for a more energy-efficient automotive fleet has encouraged the development of alternatives to the gasoline engine. Some of the more promising alternatives, like diesel and gas turbine engines, have serious emission potential (for example, NO_x from gas turbines and particulates from diesels).

Accordingly, the Committee recommends that the emission characteristics of alternative engines for the automotive fleet be thoroughly assessed and the use of combustion modifications to control emissions be evaluated. Promising control methods should be investigated in more detail.

B. Specific Needs in Chemical Processes

Because of the enormous variety of chemicals produced and used in industry (many of them environmentally unacceptable) and because of the others that are potentially hazardous but have not as yet been recognized as such, a major thrust of the EPA's efforts should be directed toward identifying hazardous and toxic substances and then ordering the efforts to control or substitute for these materials according to the appropriate priorities. The following recommendations reflect this aim.

(10) A Data Base

It is virtually impossible to predict potential pollution incidents occasioned by specific noxious or toxic materials from among the thousands of chemical consumer products, intermediates, by-products, and waste streams without an easily accessbile, accurately cross-referenced data base. Such a data system must include information on a chemical's toxicity or potential hazard; its volume of production; the processes in which it occurs as an end product, intermediate, or waste; and its ultimate disposition. Once established and updated continuously, such data would encourage the production of a list of polluting materials arranged so that such preventive or corrective action as product substitution or process changes could be implemented. Such a list should also help such organizations as the Food and Drug Administration and the National Institute for Occupational Safety and Health take advantage of a complete and current data retrieval system. Further, it should also be possible to make this system accessible to state and local pollution control agencies.

Accordingly, the Committee recommends that the EPA establish and maintain a computerized data base that includes the hazardous or toxic properties of all known chemicals; the processes in which such chemicals are used, made, or disposed of; the volumes in which these materials are present; instances of exposure to them; and their ultimate disposition.

At the same time, every effort should be made to continue arranging the control of presently recognized noxious or toxic chemical pollutants according to the severity of the hazards they present.

C. Further Data Development Needs

To complement the information compiled in the data base it is desirable also to carry out several other lines of work. Then other approaches also can be grouped under the headings "Process Change" and "Product Substitution."

(11) Process Changes

In many cases, process changes to reduce pollution already are being investigated by industry itself. This is particularly true where large volumes of products that have high visibility in the EPA regulatory offices are concerned. But, for economic or other reasons, it may be necessary for the EPA to initiate the change. To initiate these changes the Agency requires a detailed understanding of the chemical process in question.

Accordingly, the Committee suggests that as an adjunct to the data base, it may be necessary to conduct a thorough engineering analysis of the process. This analysis should include a program to determine the composition of the gaseous, liquid, and solid waste and particularly to discover any hazardous by-products that may not be otherwise indicated (for example, the presence of dioxins in products from the chlorophenols).

A further related need concerns the development of (1) analytical methods for the detection of traces of hazardous substances, and (2) rapid, economical test methods for determining a substance's toxicity, especially carcinogenicity, mutagenicity, and teratogenicity as indicated under the Toxic Substances Control Act. This latter requirement may apply not only for "new" chemicals as specified under the Act, but also for "old" chemicals which are, nevertheless, suspect.

This detailed sampling, analysis, and toxicity testing can be time consuming and expensive. Accordingly, the Committee also recommends that a search be conducted to determine whether a correlation can be established between structure and toxicity--again, with special attention to carcinogenicity, mutagenicity, and teratogenicity.

Where adequate pollution control makes a process uneconomic, it becomes necessary either to discontinue the process (and product) or to develop an economic process with an acceptable environmental impact. Since industry is normally alert to and in search of better, more economic processes, this assignment may be difficult to fulfill. In recent years, however, computer studies have focused on "reaction path syntheses" with the objective of determining the most thermodynamically and kinetically feasible reaction paths open to any given organic chemical.

(12) Product Substitution

In analyzing a product's toxicity data or the pollution problems associated with the product, it may be desirable to develop a substitution for the product itself. The data base, with its listing of a variety of product uses can help determine the appropriate substitution. Moreover, further insight may be attainable by developing a computerized structure-use relationship.

For the sake of completeness, the Committee notes that sampling analysis and toxicity testing discussed under "Process Change" are also requirements for the development of a substitute product more acceptable than the one displaced.

To supplement the development of this detailed data base the Committee makes the following recommendations:

The EPA should encourage the development of improved analytical methods for detecting traces of hazardous substances. The Agency should also direct research in analytical techniques toward the development of on-line data, or at least rapid methods of instrumental analysis that can be used for process control or monitoring. And the Agency should place its emphasis where such instruments may not now be available, as in the mixture of polar compounds or aqueous solutions.

(13) Reaction Path Synthesis

A significant amount of research is currently being done, especially by organic chemists, on computerized techniques for rapid assessment and screening of the possible reaction paths inherent in the production of organic chemicals (Wipke & Howe, 1977; Gelertner, et al., 1977). While many reaction-path-synthesis (RPS) methods yield inadequately detailed processing information, they nevertheless permit the rapid screening of different possible paths for producing a specific product. Therefore, RPS can be used to suggest process changes for those chemical manufacturing processes in which environmentally unacceptable intermediates or waste products result. Clearly, such a screening method would have to be followed by technological and economic assessments designed to establish the feasibility of undertaking any process modifications indicated.

Accordingly, the Committee recommends that the EPA closely maintain and support, in the form of contracts, the further development and refinement of computerized reaction-path-synthesis methods.

(14) Known Potentially Hazardous Materials

A number of chemical processes involving hazardous or toxic chemicals are widely used. Some, such as the commercial production of potassium cyanide, have an enviable record of safety and pollution control. Others, however, do not—particularly where small-scale operations lack technical skill or scientific knowledge and the risk of a major pollution accident is high. The electroplating industry, with its extensive use of cyanide baths, is a typical example.

The Committee believes that the EPA should seek out with requests for proposals (RFP's) and support research designed to find alternative processes for those operations using or producing hazardous or toxic chemicals. The Agency should pay particular attention to those operations in which the likelihood of an accidental discharge of these hazardous materials into the environment is high.

D. Further Recommendations

(15) The Committee recommends that the EPA form multidisciplinary task forces capable of making thorough in-plant process analyses. Such groups should be charged with developing procedures for performing plant studies or for training similar groups within an industry or organization.

(16) The Committee recommends that the EPA develop rapid, economic test

methods for detecting a substance's toxicity--especially its carcinogenicity, mutagenicity, and teratogenicity.

(17) The EPA should promote the application of computers to control and process accounting to help plant operators maintain optimal operations, minimize losses, and keep production records.

(18) The EPA should attempt to develop structure-toxicity and structure-use relationships potentially useful in ascertaining substances to be tested.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

Cardiovascular and Chronic Disease

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CARDIOVASCULAR AND CHRONIC DISEASE

I. Introduction

Unable to review all systems in depth in the time available, the Committee, nevertheless, did review the cardiovascular and respiratory systems in some detail and with the advantage of clinical specialists in those fields.

Regarding the process by which this Report was produced, the Committee offers to the Environmental Protection Agency (EPA) these three recommendations:

(1) The participants consider this process to be an appropriate way to review the status of the clinical fields and to derive research recommendations, and it, therefore, should be continued by EPA.

(2) Clinical specialists in each organ system discussed should be included in future meetings.

(3) A second meeting of the Committee (now that the Committee understands its mission and has developed a *modus operandi*) may be of greater value to the EPA than this first meeting.

II. Recommendations

The Committee has grouped its recommendations as follows: (A) Diseases, (B) Agents, (C) Methods, and (D) Organizational Issues. The recommendations themselves are numbered 1 through 12 in this Report.

A. Diseases

(1) The Committee recommends that the EPA emphasize research directed toward the development of diagnostic methods for the early detection of acute environmentally induced disease processes that may result in chronic, irreversible organ dysfunction. For example, acute myocarditis may result in chronic irreversible congestive cardiomyopathy. The nuclear cardiology technique of myocardial imaging that utilizes such radionuclides as gallium-67 and indium-111 labeled white blood cells should be capable of detecting myocardial inflammation. Similarly, granulomatous and inflammatory lung disease

and hepatocellular and obstructive liver disease are entities frequently attributed to environmental insults. The normal course of these diseases could be favorably altered by the development of sensitive new tools for their early detection.

(2) Twenty percent of the general population evinces, according to Gell and Coombs (1963), Type I allergies. Moreover, fully 5 percent of the general population has hyperactive airways disease (asthma). An overlap 20 percent will develop precepitins (Immunoglobin G) to inhaled organic materials (complete antigen or haptens) or to certain metals (for example, beryllium), and from these comes chronic disease.

The agents that cause allergic responses are widely distributed in the environment. When challenged by these agents, people with asthma, in particular, respond differently, both clinically and immunologically, than the general population. Home humidifiers and public building air systems may contribute to this problem. Some groups, such as craftsmen, have been shown to suffer acute (Type I) and chronic (Type III) pulmonary disease. Certain genetic phenotypes have been implicated in the likelihood of generating this adverse reaction. These individuals, together with nonatopic asthmatics, handle particulate material differently; therefore they are special cases in terms of "at risk."

Skin sensitivity accounts for more compensible dollars than any other work-related injury. It also reflects the ingestion of toxic and immunologically active substances by disrupting the normal processes of keratinization. Contact-sensitizing materials are heavily used in industry and can enter the food chain, air, and water in appreciable amounts. Penicillin rash from drinking milk from cows treated for mastitis is but one example here.

We recommend that major attention be given to (a) the special problem of the atopic person in an inhospitable environment; (b) the refinement of methodologies designed to detect prospectively substances liable to be banned; and (c) the identification and development of testing procedures to monitor local factors modifying sensitivity.

(3) Hypertension currently affects 30 million Americans, and various salts and other substances that find their way into the food chain and water can significantly affect the occurrence, severity, and management of hypertension. The EPA should maintain an awareness of this huge target group. With recently developed tools, the conduction system of the heart can be investigated and understood. The Committee recommends that opportunities to explore hitherto unsuspected relationships among environmental agents be exploited in appropriate research efforts.

B. Agents

(4) An increasing body of evidence suggests that indoor air quality differs significantly from the outdoor environment. Since we spend approximately 70 percent of our time indoors, the relative impact of indoor pollution and outdoor pollution on health must be assessed. Indoor pollutants warranting special consideration include particulates, carbon monoxide, nitric oxides, radon daughters, and cigarette smoke (especially in passive smokers). In addition, a growing number of man-made chemicals enter the indoor environment in the air. These include formaldehyde, aerosol propellants, solvents and cleaners, air fresheners, asbestos, and cadmium. Some chemicals enter in the drinking water including, most particularly, chlorinated hydrocarbons. We recommend that the EPA explore the possibility of developing research in these areas either under the Toxic Substances Control Act (TOSCA) or through other federal agencies with an interest in these areas.

(5) Subsets of the population, as we know, respond differently than the population in general. Many of these responses are such that the population's

susceptibility to the adverse effects of environmental pollutants increases. We recommend, therefore, that the EPA emphasize studies of asthmatics, pregnant women, children, and alcoholics. Their responses to their environments can help define the pollutant levels that cause illness in this large segment of the population.

C. Methods

(6) We recommend that the EPA review its resource allocations in terms of research efforts designed to evaluate the risks posed by hazardous agents. We believe that no form of research is more important in defining the effects of chronic exposure to low concentrations of those agents that concern the EPA than good epidemiological studies. Perhaps half of the health effects research budget should be directed toward these studies. To ensure careful evaluations of the results from large population studies and to improve the overall quality of these studies, the EPA should convene a small panel of independent reviewers expert in the field to work with the principal investigator. Such studies may, however, require long-term commitments of funds.

The Committee suggests that the major category of research funding be animal studies, which require perhaps one-third of the budget. Not only should the agency emphasize studies of the screening of effects of new materials or mixtures, but it should also provide equal support for studies designed to elucidate precisely how environmental agents act.

Finally, an important category of research deals with the clinical evaluation of persons who have been exposed, systematically or inadvertently, to harmful environmental agents. This research should evaluate long-term chronic effects of this exposure.

(7) The EPA should establish priorities on the basis of potential public health risks, as determined by the degree of injury and the size of the population affected. According to current evidence, occupational groups

are those exposed to the major risks, and these people are covered under TOSCA legislation. We recommend that the EPA, in conjunction with the Occupational Safety and Health Administration's (OSHA) record-keeping requirements, develop environmental monitoring and industrial reporting of health data, perhaps specifying a cut-off in terms of industry size. Ideally, these requirements would provide new information on human dose-response. We strongly recommend that air and water pollution health-related research be coordinated with the data obtained from occupational exposures, as a major supplement to epidemiologic studies of population groups not occupationally exposed.

(8) While experimental exposure of human subjects has yielded useful information, constraints on this type of research permit only the acute effects to be studied. But these projects are increasingly difficult to carry out and can be done only under conditions in which useful data are less and less likely to be obtained. We recommend, therefore, that to detect acute health effects of environmental exposure, the EPA develop a plan and contract for the requisite field investigations of groups inadvertently exposed through accidents or in other ways to agents of interest. The field investigation team should include personnel competent to measure exposures, to establish registries of the exposed individuals, to carry out clinical or laboratory investigations, and to undertake long-term epidemiological follow-up studies. In addition, such a team should be able to respond within hours to the particular situation which produces such a "target of opportunity."

(9) Certain diseases present models of toxic reactions. Some examples include (a) systemic lupus erythematosus, which occurs either as a drug-induced phenomenon or naturally, (b) hypersensitivity pneumonitis, and (c) aspirin

sensitive asthma, in which the patient consuming aspirin becomes highly sensitive to other insults, especially aniline derivatives.

The Committee recommends that registers of such cases be established to act as "sentinels" for acute and chronic reactions to toxic agents. Such registers need not be statewide, but could be limited to the population of cases with which certain institutions become familiar.

D. Organizational Issues

Organizationally, the EPA stands in different and sometimes varying relationships with Congress, other federal agencies (like OSHA), the public, the media, industry, and the research establishment. Research is the life blood of EPA's existence, providing information on human responses to substances in the environment and thus forming the basis for its further actions.

This Committee believes that the EPA must utilize the best that the research establishment can provide. The current relationship between the EPA and the academic research community is poor. The reasons for this situation include the EPA's emphasis on applied research; the mediocre applied research performed under EPA contracts by those outside the academic community; and the EPA's misunderstanding of the research process, including its time dimension.

The EPA's relationship with the academic community may include basic, clinical, and epidemiologic research, and it certainly will require short-term, long-term, and sometimes urgent collaboration.

(10) The Committee recommends, therefore, that the EPA develop a thorough understanding of the nature of the academic research establishment and the means by which collaborative relationships may be established under a variety of conditions. This study, itself, should be seen as an exercise in "organizational ecology," including the research establishment, the other agencies already noted, and the EPA. The greater understanding developed this way

will assist the long-term efforts that are the heart of progress. They will be especially valuable in the development of the EPA's desire to respond in disaster and other acute situations with studies aimed at the "targets of opportunity" (see recommendation 7).

(11) Correct information on the health effects of environmental agents is the EPA's raison d'etre and the public's right. The public interest is not served (and the EPA's job is rendered more difficult) when health experts disagree, and the media consequently becomes confused about "who to believe."

The Committee recommends, therefore, that the EPA establish a forum to which experts with differing views of controversial issues can be invited to make presentations and to answer questions from a panel of experts. The media should be invited to report on these events.

(12) The Committee further recommends that the EPA review its standards for substances cyclically so that it remains responsive to new research findings and to other pertinent data. The review may be linked to the forum just mentioned.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

Neurological Effects and Behavioral Toxicology

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NEUROLOGICAL EFFECTS AND BEHAVIORAL TOXICOLOGY

I. Introduction

Incidences of human exposure to toxic agents provide neurotoxicologists with an invaluable source of data for improving their risk assessments. To obtain the maximum amount of information from such exposures, however, one must utilize the best available tests for analyzing the altered function caused by the exposure.

This Committee recommends that an extensive review of the non-invasive behavioral and neurophysiological tests currently used in various disciplines be undertaken by the relevant specialists. This review should emphasize tests which provide reliable, quantitative data for assessing the functions of the human central and peripheral nervous system and should include those methods useful for evaluating the effects of exposure to neurotoxic agents throughout the human life cycle, from prenatal to mature humans and aged individuals.

The Environmental Protection Agency (EPA) should evaluate these tests of behavioral and neurophysiological effects attributable to accidental human exposures. Moreover, these tests should systematically use correlation in the same individual over a long time period. The studies should include evaluations of tissue levels, of kinetics (where possible), and of physiological functions. Where appropriate, autopsy material could contribute to tissue distribution studies and morphological evaluations of the nervous system. Available information should be used to limit these studies to those most likely to generate information on the validation of human testing methods.

The areas of neurophysiological testing to be considered should include the most sophisticated quantifiable electrophysiological measures of the central nervous system and peripheral nervous system: EEG, evoked potentials, slow potentials (contingent negative variations), potentials in peripheral nerves, and electromyogram (EMG)(Thatcher & John, 1978). The aim is to find the best research methodology for conducting tests of toxicity in humans.

The behavioral tests should include quantifiable measures of sensory and motor performance, as well as information processing, sensory-motor coordination, speech analysis, and learning and memory (Kornblum, 1973; Kling & Riggs, 1972; Massaro, 1975). The Committee recommends behavioral tests of increasing complexity in order to challenge the compensatory potential of the system under study (that is, difference thresholds as opposed to simple sensory thresholds, and choice as opposed to simple reaction times). Here, too, autopsy materials may reveal important information. Light and electron microscopy could assist in an evaluation of neuronal morphology in various brain areas. The studies should not be limited to the most popular tests, but should incorporate materials not commonly used in toxicology but widely used in other areas.

The Committee contends that too few studies of toxic exposures in humans have approached the level of sophistication available from various scientific disciplines. A few well organized correlative studies would be far more useful than large numbers of data-gathering studies that produce no detailed correlations of measures.

II. Recommendations

A critical review should be made of currently available electrophysiological and behavioral methods for use in humans but not currently utilized in toxicological investigation.

Research studies in which electrophysiological, behavioral, physiological, biochemical, and morphological measurements are correlated to evaluate the usefulness of certain measures should be carried out among both exposed and unexposed humans.

Animal studies, which can be carried out under controlled exposure conditions, permit the investigation of a wide variety of chemical agents and the use of invasive tests.

The Committee sees an urgent need for experiments that validate existing methods to enhance their predictive value for human risk. Validation requires that information addressing the effects of toxic agents on behavior, neurophysiology, morphology, and neurochemistry be correlated. This validation also requires that we understand precisely how toxic substances act. The following list reflects the Committee's consensus of information to be obtained and studies to be pursued:

(1) The existing methods in behavioral toxicology must be correlated with information from related disciplines. It is impossible to validate the existing methods without this information. Quantifiable behavioral tests should be made in concert with neurophysiological, morphological, and neurochemical evaluations of the nervous systems of animals exposed to representative toxic agents. Such studies should provide dose-response and time-response information. In addition, those factors that influence both toxicity and neurobehavioral function should be evaluated. These factors include circadian cyclicity, sex, and other interactive factors. The major areas of investigation follow: (a) behavior--sensory and motor systems, sensory-motor coordination, vocalization, complex reflexes, and operant and respondent behavior (Altman & Sudershan, 1975; Brown, 1976); (b) neurophysiology--modern quantification of EEG, evoked responses, and central nervous system and peripheral nerve responses; (c) morphology--morphometric analysis of cell structure in light and electron microscopy; and (d) neurochemistry--intermediary and energy metabolism, and macromolecular structural components.

(2) While both single-exposure, dose-response, and chronic dose-response studies are important, the test organism must also be studied for its life

span, so that data from prenatal exposure to old age are available.

(3) For purposes of test validation and risk assessment, uniquely appropriate animal species may be available. For example, some species may have distribution kinetics and may metabolize specific chemicals. Also, some species may have a morphology resembling that of humans. Therefore, we should require that the selection of species be justified and that cross-species correlations be determined. The Committee realizes that short-term support discourages the maintenance of expensive (mainly primate) or genetically unique species. Thus, in order to keep appropriate species available, it may be necessary to support colonies of such animals.

(4) A number of _in vitro_ systems have been developed to examine particular aspects of the nervous system function. Some of these systems might be utilized to detect certain types of neurotoxicological effects, and they should accordingly be evaluated.

(5) A need exists for standardized testing methods that detect neurotoxicity. The development of these methods would include the following steps:

(a) the validation of the methods with regard to the Type I (false positive) and Type II (false negative) errors associated with their use;

(b) assessment of the ability of the methods to detect neurotoxicity associated with a variety of exposure conditions, including acute, subacute, or chronic exposures; and

(c) a consideration of the sensitivity and cost-effectiveness of the methods.

At present, the data to produce this standardization do not exist.

(6) Two essential and useful purposes are served by defining the mechanisms by which chemicals induce neurotoxicological effects. First, it provides a sound basis for extrapolation across species. For example, behavioral manifestations of neurotoxicity may differ across species, even though they

are caused by a common mechanism. This difference sometimes occurs while the neurochemical and neurophysiological bases of nervous system function are held in common; the organization and expression of nervous system function tend to be species specific. Moreover, the study of toxicity mechanisms serves to clarify apparent inconsistencies in data obtained from different species, including man.

Second, in the design of testing methodologies to be applied in hazard evaluations, a critical validation step is the assessment of the method's ability to detect damage induced by a variety of different mechanisms. Therefore, the different mechanisms that can damage the nervous system must be identified.

(7) Animals exposed to toxic agents may experience either reversible or irreversible damage. The functional consequences of this damage may not be apparent in some tests if the functional reserve of the nervous system has not been exceeded (Hughes & Sparber, 1978). In these circumstances, tests designed to challenge the nervous system may be appropriate. But their usefulness in examining different types of damage needs investigating. Different challenges may be appropriate for different types of damage, and this possibility could, in turn, lead to the development of better tests of functional capacity after nervous system damage. Examples of challenges include the administration of drugs with recognized effects on central nervous system function, applications of physiological or environmental stressors, and requirement of complex problem solving. Under appropriate circumstances, a different toxic agent may well serve as a challenge.

III. Summary

Validations of the existing methods of assessing animal toxicity by correlative studies should be carried out under controlled conditions. Simultaneous non-invasive and invasive neurophysiological, behavioral, neurochemical, and morphological studies are needed, including those not currently used in toxicology.

The EPA should study both acute dose-response relationships and long-term low-level toxicity. It should emphasize longitudinal studies and comparisons of the effects of toxicity among people of various ages.

The Committee recommends the use of several animal species in toxicology studies, with special attention accorded to the unique applicabilities of certain species or strains. Long-term support of certain genetically unique species or of species in short supply (like the subhuman primates) should be undertaken.

The development and validation of _in vitro_ systems for evaluating certain toxic effects should be encouraged.

The Committee recommends that standardized tests be developed, but the members caution that validation of current methods ought to come first and that these standardized procedures must be considered experimental and, therefore, potentially flexible, given the present state of our knowledge.

Finally, the Committee recommends studies of mechanisms of toxic action to validate cross-species methodologies and to establish their relevance to the determination of toxicity in humans.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

Teratogenic and Reproductive Effects

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TERATOGENIC AND REPRODUCTIVE EFFECTS

I. Introduction

The Committee on Teratogenic and Reproductive Effects has divided this Report into two principal sections, "Laboratory Animal Studies" and "Clinical and Epidemiological Studies." These two main sections have been subdivided so as to address both the male and the female reproductive systems, and a third subdivision devoted to additional recommendations has been added to the second main section. The Committee has numbered its recommendations sequentially, 1 through 21, in this Report.

II. Laboratory Animal Studies

A. Male Reproductive Effects

Environmental exposures that cause male infertility and adverse sperm alterations that produce effects in pregnancy require further study. Environmental and industrial chemicals can cause varying degrees of infertility attributable to low sperm count, abnormal sperm morphology, and altered seminal fluid composition. The adverse effects on pregnancy outcome attributable to the fertilization of an ovum with mutated sperm can include spontaneous abortions, birth defects, and childhood diseases.

A functional blood-testis barrier, resembling the blood-brain barrier, restricts the permeability of many environmental toxins to the seminiferous tubules. Therefore, we should develop dose monitors of testicular uptake and the resulting detrimental effects before we can use systemic, *in vitro* mutagenic, and cytological findings as indicators of chemicals possessing heritable mutagenic and embryotoxic potency. This is especially true for environmental samples that contain known mutagens and fetotoxins, but because of limitation in size, samples cannot be tested in whole animal studies with pregnancy outcome as their endpoint. Dose monitors that have been proposed and should be further developed include testicular DNA synthesis, DNA damage and repair, notation of toxins in the seminal fluid, and histochemical lesions in germ cells and Sertoli cells. Dose monitors appropriate to studies in laboratory animals and humans include the sperm count, motility, and morphology. The functional consequences of altered sperm morphology should also be examined. Whether abnormal morphology implies an inability of sperm to fertilize an ovum or that the sperm are carrying an heritable mutation that can produce adverse effects in pregnancy needs to be determined.

(1) In light of these facts, the Committee suggests that the effects of exposing the testes to various environmental mutagens and toxins should be quantitatively determined by pharmacokinetic studies.

At present we have no male animal assays for heritable mutagenesis and fetal toxicity suitable for environmental samples. Assays that have been proposed include sex-linked recessive lethal tests, heritable translocations and nondisjunction tests in Drosophila; as well as specific locus, sex chromosome loss, dominant lethal, and heritable translocation tests in mice. The rodent tests represent only a limited data base, and they require high doses of even the potent mutagens. We should increase the data base these tests provide. In turn, the data base should be used to help validate the results obtained from _in vitro_ tests and biochemical tests in an attempt to develop a small-sample, inexpensive, short-term screen for male reproduction system mutagens and toxins. These attempts should include possible quantitative correlations of a chemical's potency in the short-term tests with animal tests employing adverse pregnancy effects as endpoints so that short-term tests might be used in risk assessment. The laboratory animal tests should, themselves, be validated with known human male reproductive toxins (for example, 1,2-dibromo-3-chloropropane, lead, anesthetic gases, and radiation).

(2) The Committee recommends that assays sensitive to environmental toxins that damage the male reproductive system in laboratory animals should be further developed and validated against human epidemiologic studies.

(3) The Committee suggests that studies be performed to determine the different susceptibility of the various stages of spermatogenesis to environmental insult. The susceptibility of ductal and Sertoli cells during various stages of development is another important area for further research. Alteration in ductal secreting proteins should be studied as a possible indicator of adverse effects by environmental chemicals.

(4) The EPA should formulate models that extrapolate laboratory animal data on environmental agents causing male reproductive toxicity in order to predict risk to humans. This model (or models) should take into consideration such parameters as dose-response relationships, variations in blood-testes barrier in different species, testicular and systemic metabolism (activation and detoxification), and DNA repair.

B. Female Reproductive Effects

More information is available on the effects of environmental insult on the female reproductive system than on the male, but the existing data base is still insufficient to predict human female reproductive health hazards posed by environmental exposure. The main types of female reproductive failure that should be studied include infertility and adverse pregnancy outcome. Female infertility can result from a number of interrelated events, including neurohormonal imbalance, cytogenetic damage to germ cells, disruption of the ovulatory pattern, menstrual cycle irregularity, and premature menopause. Each of these events would result in the inability of the female to produce viable ova. Adverse pregnancy outcome includes such events as spontaneous abortion, birth defects, pre- and post-natal growth retardation, stillbirth, and childhood disease states involving the nervous, reproductive, immune, cardiovascular, and respiratory systems. Mutational disorders leading to mental retardation and inborn errors of metabolism can also occur. These adverse outcomes include wasted pregnancy or the impaired capacity of the offspring.

At present, reproductive toxicity in female laboratory animals is assessed in protocol tests for teratogenicity. In classical teratology testing, exposure of a pregnant animal to the test material is limited to the organogenesis period of gestation. While this approach is effective for identifying the kind of insult leading to gross structural birth defects and embryolethality, it does not identify adverse effects on such other sensitive processes as gametogenesis in the female, blastogenesis, and functional maturation of the fetus and neonate. The Committee sees the emphasis on structural birth defects in reproductive testing as unwarranted, principally because birth defects are one of many possible adverse pregnancy outcomes and are not the most sensitive index of the human health problem. The occurrence of spontaneous abortion and functional disease states in the offspring appear to be more prevalent and sensitive indicators of reproductive toxicity resulting from environmental exposure of the human population, and these phenomena should receive more attention in laboratory animal protocol testing.

The following recommendations emphasize the need to improve the usefulness of laboratory animal test systems in predicting human reproductive health problems resulting from environmental exposure, and to identify areas in which needed information is lacking.

(5) Evaluations of reproductive toxicity have been limited primarily to assessing gross abnormalities in structural development. Such evaluations should also include adult fertility as well as stillbirths, pre- and postnatal growth retardation, and functional defects in the offspring. The exposure of laboratory animals to test agents should be extended to cover all of these results. The exposure of female animals should begin before mating to include the period of ovulation, and should continue throughout gestation to early neonatal life. The offspring should be maintained long enough to assess the potential of the exposure for causing childhood cancer. The function of the nervous, reproductive, immune, cardiovascular, and

respiratory systems should be examined during this maintenance period.

(6) The Committee also recommends that dose in reproductive toxicity testing in animals should be modeled on the human condition. Comparability in routes of exposure, dose level, and interval is essential. The highest dose level should not exceed the maternal maximum tolerated dose (the MTD, that dose level causing no more than a 10 percent weight reduction in exposed animals and no deaths); at least two lower dose levels at some standard fraction of the MTD should also be employed. We should determine the relationship between doses causing adult toxicity versus embryo toxicity. Exposures at dose levels below those causing excessive maternal toxicity would reduce the occurrence of false positive results. In all cases, the litter should be considered the experimental unit of analysis.

(7) Although any chemical that shows mutagenic activity represents a reproductive risk, reproductive toxicity can result from other, nonmutagenic mechanisms. Even if an agent is shown to have negligible mutagenic activity, reproductive studies should still be undertaken.

(8) We have a pressing need for more definitive and economic test systems for assessing teratogenic risks. Results with organ and whole embryo culture methods are encouraging, but we have insufficient validation of these systems to recommend them as standard procedures. The Committee strongly urges research efforts to develop *in vitro* teratogenesis test systems utilizing organ and whole embryo cultures rather than single cells.

(9) We find numerous examples of inconsistencies between laboratory animal results and human epidemiological studies. These inconsistencies may be resolved if the recommended principles for animal testing are adopted, and if adequately conducted epidemiological studies are undertaken. In addition, efforts should be made to identify different responses to reproductive toxicants inherent in the species. The role played by differences in placentation, number of offspring, metabolism, distribution, and excretion of drugs

should be evaluated across species so that the choice of test animals can be made with greater assurance of a valid extrapolation to humans. Studies of human embryonic and fetal tissue obtained by informed consent from induced abortions should be encouraged so that cross-species comparisons can be made.

(10) We should develop models that extrapolate laboratory animal data to risk assessments of reproductive toxicity in humans. In the absence of such models, reproductive toxicity data can be inappropriately applied or ignored.

(11) We need more information on the distribution, bioaccumulation, and metabolism of chemical agents in reproductive compartments relative to nonpregnant adult animals. The sequestration of chemical agents in follicular fluid, amniotic fluid, fetal tissues, and breast milk can markedly enhance the toxicity of these agents to the germ cells, embryo, and neonate. A greater understanding of the pharmacokinetics of chemical agents in pregnant animals would facilitate our ability to predict reproductive toxicity.

III. Clinical and Epidemiological Studies

A. The Male Reproductive System

The existing clinical and epidemiological data that relate specific environmental chemical exposures to adverse health effects on the male and female reproductive systems are limited. In the male, several studies done in occupational settings have implicated dibromo chloropropane (DBCP), lead, and chloroprene in decreased sperm counts and sperm abnormalities. But paternal exposure as a mechanism contributing to reproductive toxicity has been investigated only recently. Parameters in the male that can be measured to assess reproductive function include libido, potency, the ability to impregnate, sperm counts, total sperm counts, sperm motility and morphology, semen chemistry, pregnancy outcome, and neonatal and childhood pathology.

(12) The Committee recommends that well designed epidemiological studies be performed to investigate the effects of specific environmental exposures

on the male reproductive system. The endpoints to be assessed should include some or all of those listed above, as obtained through semen analysis and questionnaire data. Any such reproductive questionnaire should be validated among various population groups. Although the precise study design would depend on the particular exposure situation, the following principles would generally apply: (a) An appropriate comparison group consisting of unexposed individuals is essential. (b) These "controls" must be matched to the study group as closely as possible for those factors thought to be important in causing reproductive alterations. (c) The parameters to be simultaneously measured include paternal age, smoking habits, alcohol consumption, and drug ingestion. (d) These potentially confounding variables would then be stratified in the data analysis.

(13) The Committee also recommends that the investigations just described utilize study populations with substantial, precisely identified environmental or industrial exposures. Examples might include communities in proximity with hazardous material disposal sites or chemical spills, or populations residing near industrial emissions. To maximize the possibility of detecting adverse effects, priority should be given to investigations where exposures are well documented and chemically characterized and where the level of exposure is such that biological effects are suspected.

B. The Female Reproductive System

The human female reproductive system has undergone epidemiological investigations indirectly by evaluating reproductive outcome. Parameters still to be assessed include menstruation, ovulation, spontaneous abortions, stillbirths, birth defects, prematurity, neonatal and childhood pathology, and onset of menopause.

We should also undertake studies on effects of specific environmental exposures on the female reproductive system. The endpoints measured should include the parameters just mentioned, with particular emphasis on monitoring spontaneous abortion, as this appears to be the most sensitive indicator of adverse impact on the reproductive cycle.

A notification system for registering spontaneous abortions should be established. At the very least, we should record information on the age, the time of the last menstrual period (gestational age of the embryo), and reproductive history of the mother. Inasmuch as spontaneous abortion is one of the earliest outcomes of embryonic insult, and as later outcomes include stillbirths and the birth of malformed infants, the main advantage of monitoring incidences of spontaneous abortion is that it provides an early warning of these later outcomes. Populations that are at risk for the later reproductive outcomes can be identified from increases in their spontaneous abortion rates. Notifications of spontaneous abortion must be analyzed monthly for deviations from an expected number. When elevations do occur, the population of pregnant women at risk can be evaluated in greater detail by such methods as ultrasound and amniocentesis.

A critical feature in the use of spontaneous abortion surveillance as an early warning system is the separation between what is believed to be a relatively high background rate of "spontaneously" occurring abortions from those attributable to environmental insult. The application of the recommendations we make here should assist in this separation, as should analyses of abortuses for gross malformations and chromosomal anomalies. We know that approximately 60 percent of all spontaneously aborted embryos contain cells with chromosomal anomalies, and that many have gross malformations, both of which are presumably responsible for the occurrence of the abortion. We should, therefore, be studying the contribution of environmental insult to the occurrence of abortuses with malformations and chromosomal anomalies versus apparently normal abortuses.

(14) In light of the foregoing discussion, the Committee recommends a notification system for recording rates of spontaneous abortions developed

on a nationwide basis and including information on maternal age, parity, last menstrual period (LMP), and reproductive history. We need research, as well, on such factors contributing to the spontaneous abortion rate as smoking, drug and alcohol intake, maternal age, and parity before we can use an analysis of the spontaneous abortion rate as a reliable reproductive surveillance system.

(15) Analyses of the rates of stillbirths and birth defects can also provide valuable information about environmental impact on the human reproductive process. Agencies currently performing these analyses should be encouraged to continue doing so and to include larger segments of the population in their studies.

(16) The Committee recommends, whenever possible, morphologic and cytogenetic analyses of spontaneously aborted embryos. We should also study the contribution of environmental insult to the occurrence of abortuses with malformations and chromosomal anomalies versus the occurrence of apparently normal abortuses.

C. Additional Recommendations

The following recommendations apply to epidemiological and clinical studies of reproductive failure:

(17) The Committee believes that new methodologies that can be applied to epidemiological studies should be developed to measure the occurrence of ovulation, fertilization, and spontaneous abortion.

(18) Neonatal and childhood functional aberrations should be studied to determine if prenatal exposures to environmental agents result in postnatal pathologic or functional abnormalities.

(19) Record-keeping systems should be evaluated to determine how spontaneous abortions might be identified accurately other than through self-reporting. Moreover, systems should be developed and applied to specific

situations to investigate their feasibility to detect spontaneous abortion.

(20) The Committee recommends that existing data sources be surveyed and utilized, where feasible, to determine reproductive hazards inherent in environmental exposures. An example might be the use of information collected at clinics reporting abnormally numerous incidences of infertility.

(21) The Committee encourages case-control studies of identified adverse reproductive outcomes and infertility to determine the influence of environmental exposures on such endpoints as spontaneous abortion, stillbirths, selected congenital malformations, and infertility.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

Carcinogenesis and Immunologic Effects

April 24 and 25, 1979

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CARCINOGENESIS AND IMMUNOLOGIC EFFECTS

I. Introduction: Mutagenesis and Carcinogenesis--An Emphasis on Short-Term Tests

A. Discussion

Carcinogenesis, mutagenesis, and teratogenesis are scientifically and socially significant problems that demand continued investigation, especially in view of their probable relationship to environmental contaminants. Current theory states that most cancers are the result of a somatic mutation usually involving several incidents, wherein the DNA damage is not repaired to its former state. Thus, researchers place major emphasis on the correlation between short-term tests for mutagenicity and whole-animal tests for oncogenicity. Indeed, we must have reliable short-term tests as well as long-term tests for the major classes of biologic activity relevant to mutagenicity and carcinogenicity, including as a minimum, (1) gene or point mutations, (2) chromosomal alterations, (3) primary damage to informational macromolecules, (4) oncogenic transformation, and (5) toxicity.

Some mutagens can also be teratogens if the mutagen or an active metabolite can cross the placenta at a critical time during the development of the fetus. We have no convenient short-term tests for teratogenicity, but they could conceivably be developed.

A substantial body of evidence supports the general notion that some of the key aspects of inherited biochemical anomalies, aging, and atherosclerosis are associated with mutagenesis.

B. Research Needs

(1) We must continue to develop short-term tests for mutagenicity and carcinogenicity. The Committee sees a need for more precise and sensitive indicators of gene mutation, chromosome breaks and rearrangements, and nondisjunction, together with more understanding of enhanced mitotic recombination

and sister chromatid exchange and of the differential killing of repair proficient and deficient microorganisms. The potential utility of tests for unscheduled and inhibited DNA synthesis should be investigated further. We also need a more reliable test for oncogenic transformation *in vitro*. And increased emphasis should be placed on the use of human cells in these bioassays.

(2) We must make an intensive effort to demonstrate agreement among and to validate existing short-term tests or batteries of tests for mutagenicity and carcinogenicity. The validation of short-term tests for mutagenicity and carcinogenicity, by testing large numbers of chemicals of different classes, proceeds slowly and with uncertain direction. The National Cancer Institute is currently validating several short-term bioassays. But no concerted effort has been undertaken to validate and demonstrate agreement among those batteries of tests that detect the major types of biologic activity cited here as research needs 1 through 5. The tests to be employed in such batteries should receive simultaneous evaluation so that they can be used as validated test batteries as soon as possible.

(3) We must develop new short-term *in vitro* tests of greater potential relevance. Several of the Committee's recommendations focus on the further development of short-term, *in vitro* tests for mutagenesis and presumptive carcinogenesis:

Increased effort should go into the cultivation of epithelial cell types that are truly representative of the metabolically active organs that receive direct or indirect exposure to environmental toxicants.

Both directly and indirectly exposed target cell systems should be fully characterized according to their ability to activate and detoxify a variety of classes of environmental agents.

Increased effort should be made to isolate and maintain in culture the mammalian and human epithelial cells directly exposed to environmental chemicals.

The results of somatic mutation and oncogenic transformation should be pursued in epithelial cell systems, as well as in fibroblast cell systems, to produce a better understanding of the relationships among the various manifestations of the cytotoxic response to environmental chemicals. It is only through simultaneous measurement of the various biological activities of environmental chemicals that we will be able to fully characterize their toxicity and genotoxicity.

(4) We must learn to understand the relationship between mutagenesis, carcinogenesis, and teratogenesis and especially the potency of toxic substances with respect to each of these processes in various test systems. This objective entails extensive research on fundamental biochemical mechanisms; nevertheless, we should more rapidly evaluate and try to improve our concentration-response data on existing short-term and long-term bioassays. This information would facilitate determinations of the qualitative, if not the quantitative, relationship between the mutagenic, carcinogenic, and teratogenic activity of various classes of toxic substances. It would be especially valuable if quantitative potency estimates from short-term tests (for example, tests for oncogenic transformation) could be used to predict the potency of genotoxic chemicals in animals and man. Such a capability could help set priorities for the further testing of toxic substances and help guide preliminary regulatory decisions. Specific recommendations follow:

Comparative in vitro and in vivo studies should be undertaken with the same samples to provide direct information on the predictive capabilities of a variety of in vitro toxicity test systems.

The dosimetry of short-term test systems should be more quantitative so that relative potency can be more carefully assessed.

Greater attention should be focused on the relative potencies of chemicals in short-term and long-term tests to include an examination of such major variables as metabolic activation and detoxification, exposure and expression time, estimation of toxic dose, and the surviving population.

(5) We must develop better *in vivo* mutagenicity bioassays specifically for risk estimation. We have a great need to develop better means for detecting hereditary recessive gene mutations over a major portion of the mammalian genome and to determine individual variabilities with respect to this type of mutation. This information is crucial to risk estimation. The use of similar comparative mutagenesis tests *in vitro* could help in the detection and confirmation of relevant biological activity. For example, information on the concentration-response relationships between gene mutation and chromosomal effects *in vitro* could be used to predict similar relationships between these effects *in vivo*. This information might be useful in risk estimation, pending the development of better whole-animal tests. Most of our genetic tests focus on the male germ cells. Attention should also be focused on the female's contribution to mutational damage, since recent evidence suggests that this contribution may be significant.

(6) We must increase the application of short-term bioassays together with chemical analyses (especially to complex environmental mixtures). Short-term bioassays assist our investigations of hazardous substances in many ways. They can be used

(a) to predict the carcinogenicity of pollutants of unknown activity that are present in high concentrations in the environment or are highly toxic;

(b) to set priorities for chemicals to be tested in animals;

(c) to identify active fractions in environmental mixtures;

(d) to identify mutagenic metabolites in human body fluids;

(e) to determine the possible carcinogenicity of atmospheric, aqueous, or other mixtures with which humans come in contact;

(f) to determine the influence of waste and water treatment, control technology, process modification, etc.; and

(g) to aid in the selection of alternative non-hazardous chemicals to accomplish environmentally important tasks.

The evaluation of toxic substances should be correlated with how commonly they are used or how readily they collect in the environment to which man is exposed. A combined chemical and biological assessment of complex mixtures would be most advantageous and productive. Efforts should be undertaken to establish the essential working ties among analytical chemists able to provide quantitative information on component chemical fractions. Thus, the Committee makes specific recommendations:

The biological availability of complex mixtures in biological fluids and tissues should be carefully examined to obtain a clearer understanding of this phenomenon and to improve the correlation between chemical and biological data.

Collaborative and comparative studies with existing cytotoxicity, mutagenicity, teratogenicity and oncogenic transformation bioassays should be encouraged to define further their attributes and limitations in research on complex mixtures.

Increased coordinated effort should be put forth to validate groups of short-term tests as detection systems, and as confirmatory bioassays as they apply to complex environmental mixtures.

The relative potency of complex mixtures should be evaluated in short-term mutagenesis and presumptive carcinogenesis bioassays--especially those mixtures for which epidemiological information is already available.

Short-term *in situ* mutagenesis test systems (for example, *Tradescantia*) should be employed, together with other appropriate tests and chemical analytical procedures, in the qualitative and quantitative analysis of human exposure to complex environmental mixtures.

C. Highest Priorities

(7) We must validate existing bioassays (especially short-term bioassays) and develop new assays. Promising avenues for new assays include measurements of mutation in people and animals, aquatic organisms (for example, liver cancer in small fish) DNA repair, atherosclerotic plaques as a result of mutagenic event, skin and lung grafts in nude mice, and DNA damage in lymphocytes.

(8) We must learn to extrapolate doses to the human situation with more accuracy and we need better exposure data to guide risk assessments.

(9) We need to ascertain acceptable limits of such environmental pollutants as radiation and chemicals--the epidemiological studies at Hanford and Rocky Flats being useful models here.

(10) We need more toxicologists and epidemiologists (and more positions should be found for these scientists at the EPA).

(11) We need biological methods of measuring human exposure to mutagens, noting for example, the effects on sperm and the DNA adducts.

(12) We need better-designed epidemiological studies.

(13) We need to determine the effects of pollutants on a host's resistance to infectious disease (especially pulmonary disease).

D. High Priorities

(14) We must develop a battery of immunological assays.

(15) We must measure and identify groups susceptible to both carcinogens and agents that depress immunological response.

(16) We must pursue tissue analyses following carcinogen exposure.

(17) We should institute a computerized data base to enhance risk assessments.

(18) We should encourage studies of interspecies comparative metabolism and disposition of carcinogens.

II. Development of Short-term *In Vivo* Bioassays for Detection of Potential Carcinogens

A. Discussion

Clearly, short-term bioassays will be required to assess the impact of chronic exposure to potential human carcinogens or mutagens from the environment. In certain areas, we have made progress in the development of short-term *in vitro* methods of assessing the potential hazards of individual chemicals. But the metabolism and disposition of a carcinogenic or mutagenic chemical in a complex, differentiated organism like man is modified by several factors. On the other hand, the currently accepted long-term tumorigenicity bioassays are both too expensive and time-consuming to be of practical value in dealing with the large numbers of environmental chemicals presently confronting the Agency. The American Chemical Society estimates that some 44,000 chemicals are in common use in the United States. Presently, one of the more promising solutions to this problem is the development of short-term *in vivo* bioassays that combine the advantages of whole-animal pharmacodynamics with the time and cost-effectiveness of the short-term assay. In essence, short-term *in vivo* assays should be developed along molecular and biochemical parameters specifically correlated with the neoplastic process. It may be necessary to develop a number of such assays since a particular assay developed for the detection of carcinogens in one tissue (for example, the liver) may not be directly applicable to another (for example, neural) tissue. In all cases, however, the assay should be developed around some relevant biochemical event that can be measured accurately and relatively soon after treatment with the test agent. This approach would ensure a rapid and inexpensive assay and would correlate it with eventual tumor incidence in the target tissue. The Committee's general recommendations for specific developmental work in this area follow:

B. Research Needs

(19) We need to develop *in vivo* initiation-promotion assay systems. A

considerable proportion of mammalian neoplasia develops by a multi-step process consisting of at least two events, initiation and promotion. The development of tumors following treatment with the test carcinogen (initiator) can be greatly speeded up by agents known as promoters. Presently, effective promotion agents are available for two organs, skin (phorbol esters) and liver (phenobarbitol). The development of effective promotion regimens for other organs would be highly desirable since these agents both increase the sensitivity of the assay and reduce the time of tumor appearance. At present, it seems reasonable that initiator-promotion systems can be developed for the lung, bladder, and colon.

(20) We must learn to evaluate other vertebrate species as indicator organisms for specific target organs. Evidence indicates that some fish species are highly sensitive to liver carcinogens and respond faster to them than laboratory rodents. These species should be found and listed.

(21) We must learn to develop in vivo DNA repair assays. Preliminary work indicates that analysis of DNA damage and repair induced by chemical carcinogens administered to whole animals may be of particular value in determining what tissues may be target organs for a particular agent and for predicting the magnitude of the tumor in that organ. These assays can be performed in a period of from minutes to days after exposure to the test compound. The specific analysis of single and double strand breaks and endonuclease sensitive sites are techniques that should be explored.

(22) We must develop procedures for detecting preneoplastic lesions. Analysis of preneoplastic lesions (for example, papillomas of skin or enzyme altered foci of liver) have proven to be extremely valuable and reliable in making accurate short-term predictions of the eventual tumor yield of the particular organ. There are indications that analogous preneoplastic lesions are formed in other tissues (like the bladder and mammary glands) and these

analogous lesions should be investigated to ascertain their short-term predictive potential.

(23) We must investigate other disease states that may be of use in predicting carcinogenic or mutagenic potential of environmental chemicals. Recent developments indicate that the cells that comprise atherosclerotic plaques are monoclonal in nature and that such plaques are induced by chemical carcinogens and mutagens. The possible predictive value of this and other disease states possibly related to carcinogenesis should be explored.

(24) We must develop in vivo bioassays based on sperm and oocytes. Preliminary data in the literature indicate that sperm abnormality and oocyte toxicity may be useful tools for developing short-term whole animal bioassays.

(25) We should use peripheral human lymphocyte cultures as a predictive model system. Human lymphocytes, readily obtainable cells, are promising systems for the evaluation of genotoxic effects of environmental carcinogens and mutagens. Specifically, assays based on sister chromatid exchange, DNA repair, carcinogen DNA binding, and metabolism should be explored.

(26) We should use the technique of grafting or implantation and maintenance of human tissue on or within athymic nude mice. Recently, success has been achieved in the grafting of human epithelial tissue to nude mice and in the maintenance of human bronchial tissue and cells in the peritoneal cavity of these animals. These procedures offer the possibility of directly measuring carcinogenesis in human tissue exposed to chemicals in the whole-animal system.

(27) We should refine and validate non-inhalation animal models for pulmonary carcinogenesis. The only techniques currently used to evaluate the in vivo pulmonary carcinogenic potential of chemicals are whole-animal inhalation and intratracheal instillation. These methods, although valuable, are relatively expensive and time consuming. Therefore, more rapid, less

expensive, whole-animal tests would be extremely helpful. Two model systems, tracheal implants and localized intratracheal instillation, have been used for some potent, soluble carcinogens, but they must be validated for a variety of chemical pollutants, some of which are non-soluble and perhaps of low potency.

III. Risk Assessment and Extrapolation

(28) We need more basic research into the relationships of mutagenesis, teratogenesis, aging, atherosclerosis, and other related disease.

(29) The EPA should support a program to enter existing data into a computer so that species-to-species extrapolations, dose-response extrapolations, and other correlations can be made. This support will encourage more careful evaluations of the existing literature and forthcoming data.

(30) We need more basic research into the biological meaning of precancerous lesions and the implications of precancerous lesions for cancer.

(31) We need more basic research in metabolism of carcinogens. This research should include (a) comparative metabolism as related to species differences in tumor susceptibility; (b) pharmacodynamics of drugs and carcinogens in humans, rodents, and other species; and (c) detailed study of a few model carcinogens, with special attention to whether differences in metabolism occur at low and high doses.

(32) We need to determine the validity of using dose-response data from one route of exposure for risk assessments of another route of exposure (i.e., group exposure and inhalation assessments, asbestos inhalation information, and ingested assessment).

(33) We need to determine the spontaneous frequency of mutagenic events in the human population and in test animal species.

(34) We must evaluate the mutagenic risk in females as well as males to determine the relative susceptibility of egg and sperm.

(35) We need to develop methods of measuring mutagenic response in humans so that individuals with various kinds of environmental or occupational

exposure could be measured. Such methods might involve measuring DNA damage in sperm and DNA-mutagen adducts in blood cells.

(36) We need to develop better sampling methods and more reliable estimates of the exposure of humans to carcinogens. This need includes better methods of sampling human tissue (placenta, mother's milk, blood, urine, and other non-invasive techniques), as well as better measurements of exposure (personal monitors).

IV. Training and Facilities

The Committee finds a lack of environmental epidemiologists and toxicologists. Some of those currently trained do not have adequate background in environmental issues or in certain disease areas (such as epidemiologists who study reproduction).

(37) We must conduct a survey to determine the number of epidemiologists needed.

(38) We should increase the number of pre- and post-doctoral fellowships in environmental epidemiology.

(39) We should provide a number of internships or visiting scientist awards for shorter periods (from six months to two years) at higher salaries so that trained epidemiologists can develop additional expertise in a particular area (reproduction) or environmental issue. (These recommendations for toxicologists are based on the 1978 study prepared for the EPA by the Conservation Foundation.)

(40) We should increase the number of pre-doctoral fellowships for toxicology so that the annual number graduating is about doubled.

(41) We should provide a large number of post-doctoral and visiting scientist fellowships over the next five years to retrain in toxicology a large number of biochemists and biologists. This increase will help to meet the need for the approximately 1,000 toxicologists recommended by the

Conservation Foundation Report. The EPA should monitor each year a sample of recent trainees to determine if they are finding jobs readily, so that an oversupply is not created.

(42) We should develop a mechanism by which a response capability with an integrated team approach could be mounted in a short time. The Committee has in mind such environmental crises as Love Canal and Three Mile Island and a type of team approach that was mounted by the Center for Disease Control (CDC) with Legionnaires' Disease. This response capability should be integrated with the health effects laboratory so that the needs of field research are apparent to local scientists.

V. Immunology

A. Discussion

Previous studies have shown that a variety of environmental pollutants can lower animals' and people's resistance to infections, can stimulate hypersensitive responses and autoimmune reactions and enhance the incidence of neoplasms. Since the immune response is one of the important control mechanisms for all of these responses, it is necessary to determine to what degree a variety of environmental agents can directly or indirectly affect the functions of this mechanism.

The Committee concludes that the first priority in achieving this aim is to continue the development of a battery of tests capable of determining immunological consequences of pollutant exposure. These tests should be able to detect changes in people's ability to resist infections, in susceptibility to hypersensitive reactions and autoimmune responses, and in tumor surveillance and immunity. All routes of exposure to the environmental pollutants should be included, but because of increases in air contamination from transportation and energy production, a special role should be assigned to the pulmonary route. Animal models should be used for exposure and more than one species of animal should be used to increase confidence in the extrapolation of the effects on humans.

Initially, animal models should be used to develop a battery of tests that predict the immunological consequences of pollutant exposures. These studies should have broad aims. Rodents should undergo lifetime exposures to include all age groups in these studies. It would also be appropriate to include pregnant animals because of the frequency of exposure such population experiences and because of the presence of known immunodeficiencies in this population. Concurrently, human clinical and epidemiological studies can also be conducted.

Effective methods are available to study the influence of inhaled substances on immunological capabilities. Inhalation and oral exposures of experimental animals can be followed by in vivo and in vitro responses that measure the available numbers and responsiveness of specific cells of the immune systems. These cells are responsible for initiating and regulating immunological responses to infections, cancer, allergies, and autoimmunity. To a certain extent, similar techniques can be used for environmentally exposed humans.

The exposure of animals to an environmental contaminant should be followed at various times by antigenic stimulation, which can determine the animals' humoral and cellular immune capabilities. The ability to detect these capabilities is established and continually increasing because of the intense interest and activity occurring now in the immunological area. A list of in vivo and in vitro tests that may be used illustrates our current capabilities (but this listing should not preclude other tests that can increase our predictive capabilities):

(a) response of both thymus-dependent lymphocytes (T cells) and bone-marrow-dependent lymphocytes (B cells) to specific mutagens;

(b) determination of antibody-forming activities of B cells in lymphoid organs after exposure to antigens by a variety of routes;

(c) antibody-forming activity of cells after *in vitro* stimulation with antigens;

(d) recognitive activity of T cells;

(e) cytolytic activity of T cells after *in vivo* and *in vitro* sensitization with antigens;

(f) antibody-dependent cytolytic activity of T cells and macrophages;

(g) cytolytic activity of the natural killer lymphocyte (MK cell) population;

(h) delayed-type hypersensitivity responses in tissues of sensitized animals and *in vitro* correlates of these responses; and

(i) phagocytic and bacteriolytic activity of macrophages and neurophils.

These procedures and others that may be introduced later facilitate the determination of whether an animal's resistance to infection, tumors or immunological diseases is compromised, and they may also suggest which of these defenses are injured preferentially .

B. Recommendations

(43) Continue the development and application of a battery of tests capable of determining the immunological consequences of pollutant exposure.

(44) Animal models should be used to develop tests that can predict the immunological consequences of pollutant exposure. All age groups should be used and pregnant animals should be included in the studies. The animals should be exposed over their lifetimes to obtain data on chronic effects.

(45) The exposure of animals to the contaminants should be followed by stimulations that can determine the animals' humoral and cellular immune capabilities.

(46) We must develop model systems that can determine the effects of environmental contaminants on immunological responses in large segments of population with unusual sensitivity to these substances.

(47) We should develop a model system to simulate asthmatic conditions present in people. The effects of inhaled contaminants superimposed on the

asthmatic individual needs to be determined so that we understand the special problems that may be created by exposing such a stressed population to inhaled irritants.

(48) Once we have achieved acceptable reliability and predictability with chronic exposure, we should use shorter exposures in conjunction with the most sensitive of the _in vivo_ and _in vitro_ models for determination of immune capabilities. At this stage, a number of potential immunotoxins present in water or air may be used in order to determine if there are any common causal factors that contribute to perceived immunodeficiencies. Emphasis on _in vitro_ exposures of cell populations followed by their immunological activities _in vitro_ should be introduced at this time. Special emphasis should be placed on tests that can be applied to accessible and expendable lymphocyte and phagocytic cell populations obtained from people.

(49) We should use shorter exposures to contaminants utilizing the most sensitive exposure stage of the population and the most sensitive and appropriate _in vivo_ and _in vitro_ indicators of immunologic changes.

(50) We should utilize this model to compare the potential immunotoxicity of environmental contaminants.

(51) We should apply validated _in vitro_ techniques to rank pollutants for whole-animal studies.

(52) We should study the commonality of effects using animal and human cell cultures to develop a variety of inexpensive and rapid tests capable of screening environmental pollutants for their immunologic potential.

VI. Antimicrobial Defenses

A. _Discussion_

Several model systems have been used to demonstrate the effects of criteria and non-criteria pollutants on the defense mechanisms against infectious pulmonary disease in animals. Because of the great sensitivity of these mechanisms, we ought to improve our understanding of the mechanism of the pollutant effect so that the biological significance of the effects can be assessed.

Since studies have demonstrated the sensitivity of host defense mechanisms to air pollutants, water pollutants would probably also have an effect. Thus, it would be helpful to develop a model that portrays the effects of additional exposure routes.

Much of the work to date has focused on defenses against acute infectious bacterial streptococcal pneumonia and viral pneumonia. But such other microbes as Mycoplasma, which produce chronic infectious pulmonary disease, occasion a significant incidence of human pneumonia. Also, some pneumonias result from a primary viral infection and a secondary bacterial infection. Since some viral diseases result from a reactivation of mechanisms. It would be important to know if chemicals can perturb the reactivation mechanisms. It would, therefore, be helpful to develop animal models suitable for investigating the interaction of pollutants on this aspect of viral disease. Since anti-streptoccal and anti-viral defenses are compromised by pollutant inhalation, the development and validation of additional infectious disease models should provide sensitive tools for developing criteria and standards. Because some of these models would provide for relatively rapid and inexpensive tests, they would also be useful additions to testing protocols for registration purposes. Since a key part of the model development would be an investigation of the mechanisms involved in the toxicity, the information would be useful in the assessment of public health risks.

Besides models that portray whole animal defenses, application of techniques to investigate important components of host defenses would be beneficial. Numerous tests are available, like the phagocytic, enzymatic, and bactericidal activities of polymorphonuclear leukocytes and macrophages.

B. Recommendations

(53) We should determine the mechanisms of toxic effects on antimicrobial defense systems. The models currently in use should be extended to include viral and chronic bacterial infectious disease. Emphasis should be placed on those models that can be correlated with human disease.

(54) We should develop chronic animal models; and we should apply the appropriate *in vivo* and *in vitro* techniques to studies of immunodeficiencies.

(55) We should develop an animal model of human asthma.

(56) We should use shorter exposure periods to test the immunotoxic potential of a variety of contaminants.

(57) We should apply *in vitro* techniques to compare and rank effects of contaminants.

(58) We should determine the commonality of animal and human studies to develop rapid screening tests.

(59) We should develop and use infectious disease models to test resistance changes.

VII. Monitoring for Environmental Carcinogens

A. Discussion

A variety of environmental pollutants, including some carcinogens, may be concentrated in living organisms and thus be readily detectable in living tissues while still undetectable in routine samplings of air and water. The pattern of tissue concentrations is often peculiar to the pollutant--for example, Plutonium 239 in the testes, Iodine 131 in the thyroid, heavy metals in bone, and DDT in fat. Routine surveys of tissue samples from living creatures in suspected contaminated areas may improve our opportunities to detect and directly quantify human and animal contamination. Unexploited opportunities for human tissue analysis exist in autopsy-derived organ samples from community hospitals, as well as surgical specimens, foreskins, placentas, and other products of conception. The latter offer a fixed "window" on 36 weeks of human contamination.

One disadvantage of human tissue samples is that human food stores may be derived from regions considerably beyond the putatively contaminated area. Similar objections extend to comparisons of domestic animals and some food animals, except for those fed and watered exclusively from local sources. Similar objections do not extend to the resident (nonmigratory) wildlife population. Tissue studies on these animals have the advantage of the wild animals' relatively short lives that allow contamination events to be accurately dated. The variety of unique biosynthetic capacities provides opportunities for contaminant concentrations extending far beyond human capacities. The species studied should include not only mammals, but virtually all terrestrial and aquatic fauna of the study area as well. Predator studies permit analyses of the accumulation of residues in the food chain. For example, the effects of DDT on avian egg shell formation suggest that other unusual or exotic synthetic processes, such as chitin formation in insects, antler formation in deer, and many others, could provide unique opportunities for the detection of specific pollutants.

Stores of liquid nitrogen dimethyl sulfoxide (DMSO)-preserved human and animal tissues could provide an archive of previous contamination experience as well as material for retrospective mechanistic studies. Some examples might include metals, isotopes, DNA adducts, DNA repair defects, chromosomal aberrations, and total DNA content per nucleus.

B. Recommendation

(60) We need research to determine the practical utility of tissue analysis from domestic animals (pets and food animals) and wildlife in areas of putative contamination. Furthermore, the possibility of stored tissue samples

to serve as archival, reference, or investigative materials should be tested.

VIII. "Low-Level" Environmental Contamination

A. Discussion

A significant component of environmental monitoring is the establishment of maximally acceptable levels of contamination. The principal difficulty with establishing these levels is our inability to predict dose-response relationships at very low levels of contamination. Although numerous examples prevail, one conspicuous example is risk assessment in the presence of fission production contamination in the Hanford, Washington and Rocky Flats, Colorado areas. Current data do not permit an unequivocal assessment of the risks of ambient contamination levels, and both varied and controversial interpretations prevail. Available data are often fragmentary and incomplete.

B. Recommendation

(61) We need research to determine if currently acceptable levels of environmental contamination, for example, fission products in known contaminated areas of the western U.S.A., are associated with significant disease frequencies in exposed populations.

IX. Epidemiology

(62) We should conduct more epidemiological analytical research (for example, cross-sectional cohort or case-control studies) to test hypotheses where adequate scientific information exists to formulate hypotheses.

(63) We should conduct and expand epidemiological studies to include known confounding factors (particularly occupational and smoking histories) so that they are taken into account in the analysis.

(64) We should conduct a feasibility study, a problem definition study, and a pilot study as an integral part of the research planning process prior to the funding of a major epidemiological study. The planning stage

should take at least an equivalent amount of time as the study itself. We must, along the way, answer the question, "Is epidemiology the appropriate research tool to provide the data and define the research needs?"

(65) We must develop a long-range hierarchical epidemiology research plan that includes descriptive epidemiology (including upgraded laboratory and monitoring data) and ecological and correlational studies as baseline (bottom of the pyramid) information in order to develop hypotheses to be tested further. A second and more important aspect of this research is the need for more refined analytic studies (for example, cross-sectional, cohort, or case-control studies) as more refined (middle and peak of the pyramid) information for testing prior hypotheses.

(66) We must support basic analytical monitoring or the development of substitute indicators for program analysis for the purpose of defining individual exposures as a part of epidemiological research. This support could include (a) personal biological monitors (for example, for ambient air measurements), and (b) sensitive animal species as surrogate parameters (for exhibiting total body burdens of such elements as lead and arsenic).

(67) Epidemiological studies should incorporate more and new analytical laboratory data (involving, for example, liver enzymes and protein analysis), behavioral toxicology, teratogenic and reproductive outcomes (for example, spontaneous abortions as a female outcome, and sperm counts as a male outcome), or immunology in future studies, where appropriate.

(68) We must integrate environmental monitoring with the research planning for epidemiological research.

(69) We must conduct prospective longitudinal studies, particularly as a way of assessing the impact on public health of the effectiveness of an environmental change due to a regulation (standard). For cancer, it may be possible to consider certain biochemical measures that correlate with morbidity

or the predictability of morbidity.

(70) We must conduct research that evaluates the sample population as a susceptible group, (a) identifying susceptible populations, and (b) estimating the size of the group--that is, the total number at risk.

(71) We must continue to encourage the updating of currently existing cancer registries and to integrate such relevant data as occupational data, smoking history, and environmental exposures into these registries.

(72) We must encourage the expansion of surveys by the National Center for Health Statistics (NCHS), to include enviornmental exposure data, occupational data, and smoking histories.

(73) We should encourage links among such national data bases as the Continuous Work History Sample of the Social Security Administration, NCHS mortality data, and Medicare data.

X. Mechanisms

A. Discussion

Those factors that govern the susceptibility of segments of the human population to the chemical carcinogenic effects of enviornmental pollutants need detailed analysis. These data would improve our ability to assess risks. The individual factors would include age, diet, genetic complement, sex, and interaction with other agents not necessarily carcinogenic of themselves, including ubiquitous enviornmental pollutants. Differences in susceptibility to cancer are readily apparent from the disease incidence data in the human population. Experimentally, the exposure of neonatal mice to a single administration of a carcinogen or to minute repeated doses of the carcinogen have been shown to produce tumors in a large percentage of animals, while exposure to larger doses of the same compound in adult mice produces tumors in small percentages of the animals. In the human population, cancer is regarded as a disease of the aged. Dietary influences upon chemical carcinogenesis are well documented. Dietary protein concentration affects liver microsomal mixed function oxidoses (MFOS) metabolism. Deficiency states are related to decreased enzyme activity and structural alteration in the endoplasmic reticulum. The amount of dietary unsaturated fat affects tumor development. Both interspecies and even interstrain differences in susceptibility of animals to identical chemical carcinogens have been documented. Genetic susceptibilities of man to ultraviolet irradiation and to lung pathology from a lack of α-1-antitrypsin are known. The extent to which these differences affect the human population and those mechanisms whereby differences in susceptibility are made manifest should be determined. Differences in susceptibility to specific tumors vary greatly with respect to sex. Renal adenocarcinoma is about eight times more prevalent in males than in females, and animal models show similar sex differences. The sex differences in metabolism of model carcinogens possibly mediated through hormonal interaction should, therefore, be determined. The prior exposure of individuals to ubiquitous environmental pollutants (like PCB's and DDT) may cause increased activity of carcinogen-metabolizing enzymes. Conversely, prior exposure to heavy metals might lead to decreased metabolism of procarcinogens. In addition, such drugs as phenobarbitol are known to promote liver tumors in rodents. New information indicates that other organelles, such as peroxisomes, may metabolize certain procarcinogens to active metabolites. The known association of antilipidemic drugs with liver peroxisomal proliferation may explain the recently determined increased cancer risk in chronically treated patients.

B. Recommendations

(74) We must determine the metabolism of model carcinogens in specific tissues of neonates, adults, and aged animals.

(75) We must determine the site(s) of carcinogen metabolism in neonates. Chemical and structural studies in liver of neonates reveal low MFOS activity, yet neonates are most sensitive to carcinogens. We need to know how and

where this metabolism takes place.

(76) We must determine the degree of mitotic activity in neonatal organs and determine the degree of correlation with eventual tumorigenesis at tissue-specific sites.

(77) We should design studies to determine whether the increased incidence of gross tumors in aged animals may in part be due to factors that promote tumorigenesis rather than, or in addition to, overcoming the period of latency.

XI. Identification of Sensitive Populations

(78) Through the use of enzyme screening, pre-existing disease surveys, and determinations of genetic deficiency states, we can identify populations for selective follow-ups to see if they are more sensitive to environmental contaminants than the population at large.

(79) To determine the influence of newly introduced toxic agents, we must have better information on the current human genetic burden of defects and the rate of spontaneous mutations. We need similar information about the incidence of cancer and teratogenic effects. We must identify high-risk populations, either by genetic predisposition or after incidents of intense exposure, so that they can be properly protected. Pregnant women and children should receive special consideration when we monitor environmental exposure and begin to estimate adverse effects in epidemiological studies. In addition, we should use animal models to mimic sensitive populations.

XII. Pollutant Interaction with Regard to Metabolism

A. Discussion

At present, most environmental research activities center on single pollutants. Since man's environment is so complex, such a situation is obviously unsatisfactory, and in fact, the emphasis is shifting to pollutant interaction studies. This work, however, principally involves combinations of gas-plus-gas, particle-plus-particle, and gas-plus-particle. Very little research addresses the interaction of pollutants that affect xenobiotic metabolism and pollutants that are activated or detoxified by this metabolic system.

Many such interactions are possible--for example, those between common air pollutants and toxic substances. Interaction among a variety of toxic substances is also possible. An improved understanding of these relationships would lead to improved predictions of health effects (for example, additivity, synergism, or antagonism) and more efficient experimental approaches in environmental toxicology.

B. Recommendations

(80) We must establish whole-animal and *in vitro* studies to determine the interaction between a variety of toxic substances. These studies might investigate the role of induction of mixed function oxidative systems upon toxicity in lung through combined dietary and respiratory exposure regimes.

(81) We should use animal model systems to assess the extent of variation in chemical carcinogenesis brought about by the manipulation of such dietary components as vitamins, lipids, protein, carbohydrates, and antioxidants. We should also determine the effects of fluctuations in dietary components upon carcinogen activities, macromolecular binding, DNA repair, qualitative and quantitative estimates of DNA adducts, density of preneoplastic and neoplastic lesions.

(82) Using explants from compound specific organs of various animal species, including man, we should employ *in vitro* tests to determine model carcinogen metabolism.

(83) We should use *in vitro* tests to determine DNA binding and DNA repair in response to specific doses of model carcinogens in cultured cells from appropriate target organs, placentas, fetuses, foreskins, and other

expendable or obtainable tissues. This work should emphasize interspecies and interindividual variation.

(84) We should determine effects of prior, concurrent, or post-exposure to ubiquitous long-lived environmental pollutants (like DDT and PCB's) upon chemical carcinogenic process brought about by exposure to a model carcinogen. We should also ascertain the effect of prior MFOS stimulation upon tumor yield; the effect of prior MFOS stimulation upon carcinogen metabolism into activation or detoxification pathways; and the effects of concurrent xenobiotic exposure upon carcinogen metabolism.

(85) We should attempt to ascertain the effects of pharmaceutic agents upon carcinogenesis by environmental carcinogens. We should clofibrate pre-exposure and effects upon tumor yield in animals exposed to these pro-carcinogens that require N-hydroxylation for activation. And we should investigate the role of phenobarbitol in rodent liver tumorigenesis by environmental carcinogens.

(86) We need mechanism studies on the role of asbestos in tumor formation. This agent does not require activation and may not bind to macromolecules, thus the mechanism in which carcinogenesis results is of real interest.

(87) We need a determination of carcinogenesis mechanisms in specific exceptional compounds. The compound 2,3,7,8-tetrachloro-dibenzo-p-dioxin (TCDD) and others are not positive in certain mutagenesis screens, yet they are carcinogenic. What, then, is the mechanism whereby these compounds are activated?

(88) We need research that allows us to extrapolate effective pollutant concentrations from animals to man. An extensive data base exists for animal toxicological studies that utilize invasive techniques and long-term exposures, in a controlled manner that permits concentration and dose-response studies. At present, however, we have no way to extrapolate effective

concentrations and doses from animals to man accurately. To adapt the animal toxicology data base to regulatory use, we must conduct research that leads to an ability to make this extrapolation. We can make several experimental approaches to the study of air pollutants. Basically, all of these approaches involve deposition, transport, and clearance studies. The actual experiments performed depend, of course, on the pollutant. For example, most studies involving gases rely heavily on a combination of experimental studies and mathematical modeling, since ethical reasons prevent detailed experiments of gas deposition in man. In these studies, experimental features include investigations of the nasopharyngeal removal of gases in man and animals, the chemical and physical characterization of mucus in man and animals, the chemical reactions between the gases and mucus and surfactant components, the deposition of gases in animals, and complete morphometric evaluations of the respiratory tract of several species of animals. Some of this information is available now, but many gaps remain. The current data base for particles is stronger, but it has not been evaluated with a view toward extrapolation. Therefore, the first approach should be to conduct such an evaluation, which could potentially lead to additional research recommendations.

(89) We must also account for other complex factors in extrapolation. Such factors as the effects of exercise could be analyzed in mathematical models. Others, like deposition and clearance in diseased lungs, would require experimental data. Since progressive toxicity seems liable to occur during chronic exposure and results in a progressive alteration of deposition and clearance, a dynamic situation needs to be addressed. Furthermore, man exists in a complex environment, so dietary influences (for example, the neutralization of H_2SO_4 by ammonia in the breath) and the interaction of pollutants (particularly between gases and particles) require investigation. Another major area requiring research is the dosimetry of complex particles,

including those with carcinogenic activity. When a given concentration of a complex particle enters the body, various components of this particle may be transported differently and experience different metabolic fates. A study that addresses this problem should consider bioavailability. A concerted effort could increase the reliability of a data base on the health effects of particles on animals, and this data base could then be used to help set environmental standards. Thus, the full array of pollutant concentration effects that occur in man might be quantifiable.

These research recommendations apply primarily to inhalation exposures. But the Committee also considers it important to provide dosimetry information that permits the extrapolation between _in vitro_ and _in vivo_ exposures. This information would aid in the design of _in vivo_ studies.

XIII. Exposure Conditions

A. _Discussion_

The exposure route can be the most important aspect of an experimental design since it can be the prime determinant of the minimal effective concentration and dose and can even be responsibile for the effect observed. For example, there was a 200- to 400-fold difference in the minimal effective concentration of cadmium and nitrogen between the aerosol and the parenteral delivery of the pollutants. Still other examples indicate the importance of the route of entry: The inhalation of silica can cause an extreme suppression of breathing; however, when given by injection, immunostimulation is the result. Another study has suggested that either acute or delayed neurotoxic effects occur, depending on whether the route was oral or dermal. From this and other research, we can see that to assess pollutant effects accurately, we must make the experimental exposure match the route of the ambient exposure, even if only a proportionately smaller dose is delivered via a particular route.

Understanding the mechanisms responsible for these findings would develop improved and more rapid bioassays and make judgments on the routes of exposure for protocol testing for registering toxic agents.

Explorations in this area would build upon our knowledge of pharmacokinetics and the metabolism of xenobiotics. For example, lung metabolism evinces some significant differences from liver metabolism. Delivered orally, a chemical could be metabolized by gut microflora. In cases where the metabolite of a chemical is the toxic species, these differences in metabolism could have a significant impact. For chemicals not experiencing biotransformation, the route could be important for other reasons. For example, transport, clearance, and the solubilization of chemicals on complex particles and chemical interactions with a given cellular type could be expected to differ according to the route of the exposure. These complex relationships require further investigation before an accurate extrapolation can be made.

B. Recommendations

(90) We should improve the health effects data base for criteria and non-criteria air pollutants.

To meet the requirements of the Clean Air Act, National Ambient Air Quality Standards (NAAQS) are being reevaluated every five years. This continual effort requires improvements in the data base. While a complete enumeration of data gaps to be addressed is beyond the scope of this Report, the Committee finds a critical need to continue research on criteria pollutants, as well as on those that present a potential public health risk. In general, the Committee recommends research in the following areas:

(91) We must fill specific data gaps (for example, we need complete concentration-response studies where the minimal effect level is unknown; and we must replicate the important studies).

(92) We should use exposure modes that mimic ambient conditions (for example, acute, intermittent, and chronic exposures, and diurnal patterns).

(93) We should investigate pollutant interactions.

(94) We must provide methods to extrapolate our findings.

COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

How, What, Where, and In What Form

April 24 and 25, 1979

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HOW, WHAT, WHERE, AND IN WHAT FORM?

I. Introduction

Man's environment contains both chemicals of geochemical origin and synthetic chemicals produced by manufacturing processes and disseminated in the use and disposal of industrial products. Various physical, chemical, and biological processes in the environment cause these chemicals to move, sometimes for long distances, and this movement can substantially alter these chemicals. The alterations may result in decreases or increases in toxicity, while the movement may bring the chemicals into contact with parts of the ecosystem where they can affect organisms, processes, or materials important to man.

Faced with a multitude of chemicals in the environment, the Environmental Protection Agency must decide which chemicals to control and how to control them. It needs to know their effects (preferably in terms of dose and response) on man, on other organisms needed or desired by man, on living systems needed or desired by man, and on materials and objects important to man. And the EPA needs to know the value to man of the organisms, objects, or processes being affected, as a basis for deciding whether control is desirable; how best to interdict the substance; and the sources, movements, and transformations of the chemicals that take place in the environment.

Later parts of this Report address research on the effects of chemicals directly on human health and the effects on particular ecosystems which are less directly, but still profoundly, important to man (for example, terrestrial, agricultural, and marine ecosystems). The first part of the Report deals specifically with understanding the movement and fate of chemicals that traverse more than one medium, and the effects that may result in the course of such movement. It calls attention specifically to the intermedia transfer of pollutants and to the effects and processes at the conjunctions of these media.

The Committee has arranged its recommendations to run sequentially, 1 through 18, in this Report. The arrangement of the recommendations reflects no particular overall ordering of priorities. Within each subdivision, however, the recommendations mentioned first have generally been accorded the highest priority.

The recommendations on acid rain and CO_2 lie beyond the Committee's assigned area. They are included, however, as valid recommendations for consideration by the EPA both as a part of this research project and the EPA's research responsibilities.

II. Global and Regional Problems

Some environmental problems cannot be dealt with in terms of single-media systems. These problems are often regional or even global in extent. Some biogeochemical cycles (for example, the carbon and nitrogen cycles) are being altered by man's activities--in some cases, with profound effect. The Committee singled out "acid rain" and "atmospheric CO_2" as problems that deserve continuing, intensive study. The Committee has, in addition, suggested particular facets of the problems that need to be studied. We call attention to the need for considering the transfer of pollutants between or among media, to reactions that take place at the interfaces between these media, and to the role of biota in both the transformation and movement of chemical substances.

A. Acid Rain (Sulfate)

The acidic characteristic of rainfall has killed organisms in lakes in many parts of the world, including the eastern United States. Forests and other terrestrial ecosystems also may have been adversely affected through changes in soil properties caused by acid rain.

The acid component of rain is predominantly sulfate--sulfuric acid and other sulfates. (It also contains nitric acid, other nitrates, and other less acidic constituents.) The sources of the sulfates are largely fossil-fuel-fired power plants and smelters, perhaps thousands of miles distant. The power plants emit SO_2 which, during atmospheric transport, becomes SO_4.

What to do about the acid rain problem, now of international importance, appears straightforward from the technological viewpoint. The sulfur oxide emissions must be abated, because once the sulfur oxides enter the atmosphere, they cannot be scavenged before they cause damage.

(1) The Committee recommends research into the effect of acid rain on various soil types and conditions in order to estimate the time over which the growth of soil biota will be affected. This research would also provide recommendations for soil treatment to ameliorate the deterioration of forests and the growth of animals and organisms living in forests. (We have here a good example of intermedia transfers, interfaces, and complex, synergistic effects.)

(2) We also need monitoring at selected, representative sites to measure the change of acidic properties of lakes and rainfall and of the species abundance and diversity therein.

(3) The Agency should promote research on life within lakes to determine its tolerance of or susceptibility to acidity introduced by acid rain.

(4) We need research that refines our knowledge of the atmospheric transformation mechanisms producing acid rain; the rates of precipitation onto soils, waters, and vegetation; and the composition of acid rain along its pathway.

(5) We need an integrated risk assessment of the socio-economic aspects of the effects of acid rain and available or potential controls. (An important difficulty here is that the damage occurs in political entities far

removed from the sources of the acid rain.)

(6) We need control technology research aimed at developing inexpensive and feasible methods for desulfurizing fossil fuels prior to combustion or removing the sulfur oxides prior to emissions from the stacks.

B. Carbon Dioxide (CO_2) and Climate Change

Atmospheric CO_2 concentrations have been growing exponentially since the beginning of the industrial revolution, around 1860. These concentrations are caused by the combustion of fossil fuels. Deforestation around the globe has also contributed significantly to this increase.

Atmospheric CO_2 alters the radiation balance through what is called the "greenhouse effect," and its concentrations may double to about 600 ppm by the year 2030 (and quadruple as a minimum by the year 2100), causing an increase in global average midlatitude temperatures of about 2°C (at least 4°F). The temperature increases may be less at the equator, but between 5 and 10°C in the polar regions. Such warming could melt polar ice, leading to a rise in the sea level.

The greenhouse effect will affect not only the average climatic condition, but also its variability, including winter and summer extremes and latitudinal variations. Precipitation and wind patterns are also expected to change. Such climatic change will primarily affect agriculture and water supplies, as well as natural ecosystems.

A multi-agency research and monitoring effort centering on the greenhouse effect has already been initiated. The Department of Energy has taken the lead in CO_2 studies. A U.S. Climate Program Office has been established within the National Oceanic and Atmospheric Administration to coordinate all climate research and monitoring, including the CO_2 program. The EPA's participation should be based on the Agency's mission and expertise and, as much as possible, on the output produced by the other agencies involved.

(7) Thus, the Committee recommends that the EPA initiate or support research into the sensitivity and survivability of ecosystems and organisms exposed to extremes of climate variability (winter and summer), as well as the development of an early warning tool to guide decision making in the event of substantial climatic variability.

(8) We must also evaluate water supply quantity and quality under various climatic variability conditions and look, as well, into the likely user requirements.

(9) And most immediately, we must assess the state of technology for (inexpensively) preventing CO_2 emissions from fossil-fuel plants.

III. Ecosystem Research in General

A. Long-term Research

To assess the environmental impact of chemical and other products of our society, we must understand the natural, temporal patterns of plant, animal, and complete ecosystem populations. An environmental impact can, after all, be defined as something that changes these natural patterns.

Moreover, biological populations and ecosystems may undergo such episodic events important to human welfare as insect outbreaks and sudden small mammal abundances. Forecasting these episodes requires long-term monitoring. Determining the accumulation and fate of toxins in the environment also requires long-term monitoring.

Long-term study is necessary not only to EPA, but to many other government agencies as well. If each agency established a separate, non-compatible monitoring program, it would be both economically and intellectually inefficient. The National Science Foundation (NSF) has begun long-term ecological research to establish a compatible series of measurements at a number of sites across the country. The EPA might obtain useful long-term measurements more efficiently by acclimating itself to this program and lending the participation of its personnel and finances. Such support would extend the NSF program to include measurements directly relevant to the EPA, and it would help ensure that, where possible, its own data would be compatible in format, technique, measurement frequency, and storage and retrieval capability, to that obtained in the NSF program alone.

(10) To meet its needs for long-term measurements, the EPA should request the cooperation of and participate in the long-term ecological research program now supported by the National Science Foundation. This cooperation might include the assignment of EPA personnel and financial support for aspects or extensions of the program. Where possible, the EPA and NSF data should be made compatible.

B. The Study of Microcosms and Other Controlled Systems

Field measurements and observations are time consuming and difficult. Field experiments are, moreover, sometimes impossible to conduct. Controlled studies in simplified, artificial microcosms may help elucidate certain ecosystem situations. They have been used successfully in studies of pesticide distribution and degradation in soil-aquatic and plant-animal systems. Their relative simplicity and low cost invite both replication and additional studies of the effects of changes in one or several variables in the experiments.

(11) Thus, the Committee recommends a systematic exploration of microcosms and other controlled systems to establish the most appropriate conditions and limitations for the use of these tools in the assessment of environmental impact. Studies should be undertaken to utilize arrays of such systems to explore different aspects of the movement and alteration of single chemicals and combinations of chemicals under an expected range of environmental conditions. Verification through field studies should be part of these efforts.

C. Integrative Ecosystem Measures

Sustaining life on earth is a function of ecosystems, not of individual organisms. Therefore, environmental impact must be assessed in terms of its effects on entire ecosystems. Furthermore, the response of an ecosystem may provide a simpler, more integrative measure of environmental impact than a species-by-species measurement. But the study of ecosystems is a new science, and we have yet to determine what the appropriate, most efficient, most information-rich, most unbiased, measures of ecosystem state are. Well-directed research might help us make this determination.

For example, a toxic compound might change either all of the organic matter or the rate of change of some of the organic matter in an ecosystem. A toxin might change the species diversity or the rate of chemical elements flux through the system. Ecologists tend to choose simple, single measures applicable to particular questions. For example, "net production" or "total energy flow" have often been used as ecosystem measurements. Some claim that these are sufficient for any question, but claimed is far from proved. Ecologists, in short, have yet to find the equivalent of a physicist's pressure, temperature, and volume, and an adequate ecosystems measure is not a simple scalar quantity. On the other hand, a total description of an ecosystem, such as the abundance and activities of all populations, is in practice unobtainable. Appropriate measures must lie somewhere between a total description and a single-scalar measure. Therefore, we need research aimed at finding appropriate, integrating measures.

(12) Thus, the Committee urges the EPA to support studies to determine appropriate ecosystem descriptors. This research should be directed toward determining the response of ecosystems to perturbations induced by toxic compounds, heat pollution, and other environmental alterations.

D. Relatively Simple Conceptual Models

In the past, researchers have emphasized detailed compartmental models and vast parameter sets. But quantitative prediction is often neither possible nor necessary. Appropriate, simple, general models can, in fact, lead to qualitative predictions of the stabilizing or destabilizing effects of altered energy flows caused by pollutants at various trophic levels. These predictions are "soft"; they specify neither quantities nor time with precision. Rather, they concern the ultimate fates of systems in terms of stability, resilience, and survival. An analysis of this type of simple model resulted in Rosenzweig's "paradox of enrichment"--that the addition of nutrients or energy to a system can cause destabilization (Rosenzweig, 1973). This destabilization, of course, is exemplified by eutrophication.

(13) Thus, the committee suggests that the EPA support research on the extent to which efficient predictions of pollutant effects can be derived from simple conceptual ecosystem models.

E. The Use of Non-Quantifiable Data

Decision making on the basis of non-metric, "best judgment" information by knowledgeable experts is characteristic of many areas of environmental concern. For example, to assess the impact of a new plant or oil refinery on a local ecology may require unreasonable financial resources. In such a situation, conventional scientific, or "metric," thinking may be infeasible, while a structured description may extract the maximum insight from a qualitative, but intellectually disciplined, data set.

General mathematical languages in algebraic topology are available to help in the task of structural description. They have been well tested in a variety of planning and management areas, but not in environmental analyses. Their utility as aids to decision making in areas of acknowledged difficulty should be explored. Moreover, the EPA should communicate its interest and concern in these areas to other agencies of potential support, including the NSF (applied mathematics) and the Social Sciences Research Commission (Committee on Mathematics in the Social Sciences).

(14) The Committee, therefore, feels that the EPA should support and encourage the development of formal methodologies for structuring, analyzing,

and assessing non-quantitative, qualitative information, and encourage applications of this information and experiments addressing environmental problems and questions.

F. Toxic Chemical Transformations, Ecosystem Thresholds, and Population Sizes

The passenger pigeon fell rapidly from extremely large numbers to extinction, while the whooping crane reached a population size of 14, but seems to be recovering. Was the passenger pigeon subject to some threshold population size--quite large--below which the entire population was certain of extinction? Or might the rapid downward trend of the species have been reversed if only two individuals had been saved?

Research into questions like these is crucial to assessing the acceptable risks to local populations as well as to entire species. Why do some species persist for long periods at low abundances and others become extinct when relatively abundant? What are the general rules relating the characteristics of a species to its minimum permissible size? How are such population levels related to or affected by the state of the ecosystem? It is the sense of the Committee that a proper assessment of the impact of toxic compounds on biota requires a better understanding of these issues.

(15) Thus, the Committee recommends that the EPA sponsor research on the biogeochemical transformations of toxic chemicals. That is, the Agency should support studies of how the movement of a chemical among a variety of ecosystems leads to by-products and accumulation sites that could not have been predicted from the chemical's behavior in a single ecosystem. Sulfur dioxide released from power plants and smelters is an example of such a problem.

(16) The EPA should also sponsor research on the threshold effects in ecosystems and, in each project that concerns the ecological effects of a toxic compound, the Agency should attempt to determine whether a threshold is or is not a useful concept. For example, we often hear the argument that

organisms can sustain a chronic low-level dose of a toxin, but are killed by any amount above some threshold. Others argue that there is no such thing as a threshold in any ecosystem; rather, all doses have some adverse effect. We do not know for certain whether threshold is ever a useful concept; thus, the threshold concept could be the direct subject of study.

(17) The EPA should sponsor research on the minimal permissible population sizes of biota; that is, sizes below which a population has an unacceptably high chance of extinction.

G. The Biological Implications of Habitat Alteration

Within an ecosystem, each organism inhabits a particular environmental space, called its habitat, in which it carries out its life activities. Any alteration of this space, positive or negative, can affect the abundance of the organisms living there. Environmental improvement of an ecosystem may expand the range of the habitat for particular organisms, including pest species. For example, the cleaning up of streams and rivers may provide more favorable environments for black flies and increase their density (Merritt & Newson, 1978).

Sewage sludge and treated wastewater effluents which contain toxic metallic and non-metallic elements, organic substances, and pathogenic microorganisms may be used in agriculture. This application affects the habitat and changes the populations of organisms in the habitat. In addition to toxicologic effects of these elements on vegetation, animals, or humans in the food chain, the physical modification of habitats may change the biotic diversity and, therefore, the decomposition processes (Anthony, et al., 1978; Samson & Lewis, 1978). These changes may, in turn, lead to increases in the abundance of disease vectors, changes in the biology of pathogenic organisms, and thus changes in the epidemiology of local zoonoses (diseases transmitted from animals to man).

(18) Thus, the Committee suggests that research should be undertaken on the unintended results of environmental alterations. For example, we need (a) an understanding of how habitat alterations resulting from pollution and pollution abatement affect disease vector biology and local zoonoses; and we need (b) to provide basic data concerning the process of ecological changes in areas altered by sewage sludge and treated wastewater applications.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

CRITICAL TERRESTRIAL ECOSYSTEMS: LAND AND AIR

April 24 and 25, 1979

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CRITICAL TERRESTRIAL ECOSYSTEMS: LAND AND AIR

I. Introduction

The research priorities identified by the Committee on Critical Terrestrial Ecosystems: Land and Air are based on the assumption that a major role of the Environmental Protection Agency is to determine how environmental hazards alter terrestrial ecosystems in ways that threaten man and his environment. The Committee agreed that three general areas of research deserve special attention: (1) documentation; (2) prediction; and (3) minimization of the effects of environmental hazards on terrestrial ecosystems. Within each of these major areas, the Committee formulated specific research recommendations. These recommendations, numbered sequentially 1 through 9 throughout the Report, are preceded by justifications and discussion.

II. Recommendations

A. Documentation of Effects

Sampling and analysis. The need for reliable documentation of the effects of environmental hazards on living systems is basic to the management of environmental problems. Documentation provides essential information about the components of an ecosystem that are affected and the nature and extent of those effects. We need to develop better methodologies to document, predict, and quantify the impact of environmental hazards on ecosystems. Moreover, if these methods are to be used continually, we must consider the costs and time involved in analysis.

(1) Thus, the Committee recommends that the current efforts to develop a series of sampling and analysis programs for contaminants of concern in soil and for domestic and natural ecosystems be improved. Research efforts to increase analytic sensitivity and specificity for each contaminant should

be continued. In the case of routine analysis, standardization for quality control of analytical data must also be developed.

Long-term monitoring. A long-term data base is needed as a standard against which to measure ecosystem changes. The continued monitoring of functional aspects of ecosystems may permit some anticipation and partial assessment of future environmental contaminants before they become serious problems. The widely known problem of acid rain in the Eastern United States was first discovered in the Hubbard Brook research program that was monitoring (among other features) year-to-year variations in precipitation chemistry. The detection of a substantial increase in the acidity of rain water was possible only because ten years of routine measurements were available.

Ideally, monitoring should be established in a wide variety of geographically distinct ecosystem types--urban (for example, city parks) as well as rural, managed (for example, agricultural ecosystems) as well as natural. A *minimum* list might include the following:

Natural Ecosystems

1. an Eastern forest
2. a Western (coniferous) forest
3. a grassland site
4. a desert site
5. a marsh site

Managed Ecosystems

1. corn
2. soybeans
3. cotton
4. a grazing ecosystem (cattle)
5. an urban park

To increase efficiency and reduce duplication of effort, the new research should be coordinated with established ecosystem studies like those at Hubbard Brook and Oak Ridge whenever possible. The variables measured will differ from ecosystem to ecosystem. Moreover, the analyses should be conducted at many levels of biological complexity. Ecosystem level measurements might include stream water chemistry (heavy metal, cation, nitrogen, and phosphorus content, for example); decomposition rate of litter; some measure of primary production, such as litter fall; and the diversity of some segments of the biota.

Species-level measurements could include the population dynamics of representative plant species; the population dynamics of one or two carefully chosen animal species (perhaps a consumer and a decomposer); and lichen density and diversity.

Physical level measurements could include soil chemistry variables, meteorological data, and precipitation chemistry.

(2) Thus, the Committee recommends a research program to develop a data base for monitoring the long-term health and vigor of natural and managed ecosystems. Such research should, moreover, be conducted on permanent sites.

B. Prediction of Effects

The quality of advice available from the EPA would improve in proportion to the capacity of environmental science to predict and forecast ecological phenomena accurately. Research on short-term prediction is already underway and certainly should be continued. But such efforts help only to predict the course and intensity of a crisis. Therefore, it would be better to develop the ability to make predictions in time to avoid crises in the first place. As in aspects of individual health, prevention is preferable to a cure.

Reconciliation of theory and practice. Environmental science is susceptible to mathematical modeling and laboratory analysis. Other sciences have shown that these methods can lead to a better understanding of the processes underlying scientific phenomena, and with an improved understanding of such phenomena comes an improved ability to predict them, manage them, and alter them in beneficial ways.

The problem in environmental science is not that such studies have not been conducted. They exist in some abundance. The problem has been that they are irrelevant until tested in real environments. In environmental science, the field investigator tends to go one way, the theoretician or laboratory worker another. The field experiment has not often tested the theory and so has neither improved it nor caused it to be rejected. Similarly, the theoretician has not often couched theory in testable terms.

(3) Therefore, the Committee recommends that theories and laboratory conclusions that offer promise of better environmental prediction or management be identified. We also urge the Agency to support field research projects that test such theories and conclusions.

Convergence studies. A technique for discovering which properties ought to be predictable is called a "convergence study." In such a study, the investigator compares independent ecosystems in similar biophysical environments and sorts out those variables that yield similar values in these places from those that yield dissimilar values. The latter are usually under historical influence and cannot be reliably predicted; the former are probably predictable steady states, and the research focused upon them should be the most productive.

To yield useful answers, convergence studies must be conducted on the most independent ecosystem replicates available. This means conducting research on different continents simultaneously, because only when the organisms of the different places are not closely related can one be reasonably certain that the geological similarities are really predictable from the environmental pressures.

In addition, these studies should be conducted on mature ecosystems, but this does not exclude successional series with a host of species and interactions adapted to take advantage of temporary environments. It does, however, mean that recently produced environments associated with human civilization are not safe for such studies. Results obtained from the mature ecosystems can be applied to the recent ones, but they cannot be derived from them.

Convergence studies have been attempted only since the middle 1960's, but they have already met with some success. Many were conducted under the auspices of the International Biological Program, which compared the properties of Mediterranean ecosystems in California and Chile, and desert ecosystems in Arizona and Argentina. Many of the properties these investigators chose to measure showed the effectiveness of their approach. Such items as trophic structure, productivity, and species diversity were particularly enlightening. But undoubtedly, new measures of greater usefulness to the EPA will be developed as research progresses.

(4) Consequently, the Committee recommends that convergence studies comparing the ecological properties of mature ecosystems in similar environments, but on different continents, be undertaken to discover those ecosystem properties that are predictable, and to focus future research on them.

Stress. Since biological entities can respond in a finite number of ways, we start with the assumption that a response to a specific stress can be predicted by responses observed in the past. But one must identify those responses at every biological level (for example, species, community, and ecosystem) and physical level (for example, soil and topography) readily affected when the system is under stress. Certain responses to stress have already been documented. They include reduction in species diversity in stressed communities, productivity of less value in domestic and natural ecosystems, and altered vertebrate physiology reflected by changes in behavior, blood pressure, and endocrine balance.

In attempting to identify general stress responses, one should address those variables considered sensitive and important to man and his environment. Biological variables that could be included are productivity; qualitative factors like vitamin content of vegetation or elevation of levels of such toxic substances as alkaloids; altered population composition; and increased susceptibility to disease. Another stress response to be considered is physiological or genetic adaptation. This adaptation can result in individuals that can tolerate the environmental stress but are otherwise less desirable. Physical variables that might be responsive to stress and should be studied could include the erosion, compaction, or fertility level of the soil.

(5) The Committee recommends that the Agency identify responses of species or terrestrial ecosystems that occur as a result of stress. A broad spectrum of stresses should be tested to determine whether general stress responses can be identified, and for which organisms.

Environmental processes. Environmental processes govern the transport and compartmentalization of contaminants in air, water, soil, and biota. The lack of uniformity of soils among and within geological areas makes it necessary to predict the retention and degradation of contaminants from studies of relatively few soils or from synthetic sorbers.

(6) Thus, the Committee recommends that research on basic environmental processes be conducted to develop models for predicting the rate-limiting processes (like degradation and soil adsorption) that have the greatest influence in determining the actual disposition of the contaminant of interest. Research should also be conducted to relate contaminant retention and degradation to soil properties. This research should involve both modal soils and synthetic materials to simulate soils.

C. Minimization of Effects

Contaminant concentrations. The contamination of terrestrial ecosystems does not preclude their use in a controlled agricultural or natural system, but it does dictate that precautions be exercised. Consideration must be given not only to scientific solutions to pollution problems, but also to defining those economic and social constraints that preclude the implementation of suitable mechanisms designed to deal with environmental hazards.

The affinity of soils for many toxic materials makes them an effective receptor, and this characteristic, in turn, helps protect air and water quality. But some contaminants may be concentrated in soil and become incorporated in food chains. Consequently, injury may result to vegetation, animals or humans in the food chain. To protect human health, therefore, we must decide whether to apply the contaminants in high concentrations to limited land areas or to distribute them widely.

(7) Thus, the Committee urges the Agency to conduct an inventory of local and national ecosystems to determine the cost-benefit as well as the human health impact (population exposed and relative risk) of different contaminant concentrations in the soil.

Disposal sites. The use of specific sites dedicated to the disposal of hazardous materials often meets with public resistance in the areas where the sites are located. Therefore, we need to integrate sociological considerations into decisions regarding environmentally acceptable disposal sites.

(8) The EPA should investigate the preferences expressed by people regarding sites managed primarily for disposal.

Plant tolerance. Economic considerations often force us to accept certain defined levels of pollution (for example, the 0.12 ppm oxidant standard). The use of tolerant plant material may permit higher pollutant levels with minimal cost to grower or consumer. Identifying mechanisms of tolerance would allow us to incorporate such factors in plant breeding programs.

(9) Consequently, the EPA should investigate the adaptations of various plant species to environmental contamination so that we can breed for plant cultivars tolerant of environmental contaminants. We should also investigate the mechanisms of tolerance and adaptation.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University

and

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Critical Ecosystems: Water

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CRITICAL ECOSYSTEMS: WATER

I. Introduction

The determination of what constitutes a "critical ecosystem" depends upon many factors, not the least of which is the perspective of the evaluation. In this Report, the Committee considers an entire watershed to be the critical aquatic ecosystem, and while recognizing that watersheds do have regional characteristics, we propose that the sensitivity of these systems is directly related to population pressures.

To assess the impact of population pressure on a given watershed, one must consider a number of factors. One of these is the physical characteristics of the watershed itself, including its geomorphology, volume and turnover rate, and ground water supply

Another factor is the population patterns throughout the area with the varying demand for water these patterns imply. For example, how much water is needed for drinking, agriculture, recreation, cleansing, and industrial use? And what are the pollutants that these different population patterns generate? Thus, the urban ecosystem, the natural ecosystem, and agriculture are inexorably joined.

The biological characteristics of the watershed must also be addressed, especially in terms of speciation and productivity, and a final factor is the resiliency of the ecosystem--that is, the disturbance it can withstand before the water supply and quality are threatened.

The Committee has based the research recommendations that follow on these considerations, and it has determined priorities according to the degree of impact it judges perturbation to have on the watershed as a whole. The Committee has categorized sources of pollution in aquatic ecosystems into five major types: (A) agriculture and silviculture; (B) municipal wastes;

(C) industrial effluents and wastes; (D) transportation; and (E) the resiliency of aquatic ecosystems. It has numbered its recommendations sequentially, 1 through 21, throughout this Report.

II. Recommendations

A. Agriculture and Silviculture Pollutants

Nutrients. Nitrogen and phosphorus supply generally limit production in aquatic systems. Nitrogen is especially important in coastal waters, while both nitrogen and phosphorus appear in fresh waters. Their load attributable to human activity ranges from wastewater treatment to fertilizers from farm lands and often determines the water productivity in a drainage system. The effects are felt in upstream lakes and wetlands but are concentrated in the estuaries, which are the final repositories of land drainage.

Nitrogen budgets have been partially or completely determined for a few natural ecosystems, including (for example) Hubbard Brook Forest and Great Sippewisset Salt Marsh. These budgets include data on rain input, weathering, and ground water. Data also exist for the output of sewage treatment systems, municipal runoff, and industrial wastes. Agricultural studies could provide estimates for farm runoff, and current work by soils scientists should at least suggest order-of-magnitude estimates for nitrogen fixation and denitrification. The same sorts of statements can apply to phosphorus. If all available estimates were combined for a complete watershed, we would have an initial approximation of a nutrient budget or model for that watershed. This approximation would have two general uses: (1) as a research tool to point up the deficiencies in our present knowledge which keep us from constructing a much more accurate budget; and (2) as a management tool. If we could point out what the most important sources and sinks within a complete natural system were, we could easily see how regulatory efforts should be adjusted to maximize their benefits (for example, we would recognize exactly how important secondary sewage treatment might be at different points within a watershed).

(1) Thus, the Committee recommends that a nutrient budget, ideally for nitrogen, be constructed for a complete watershed, including its estuary, from all available data. A simple model for a nutrient in a watershed should certainly be constructed if enough data are available to justify the exercise. Subsequently, the Environmental Protection Agency might focus attention on such questions as the importance of river floodplains (for example, a lack of levees and the effects of channelization) to nutrient budgets, or the effect of managing wastewater treatment to change the ratio of NO_3 or NH_3 in effluents.

Biocides. Biocides include those materials used to control organisms categorized as pests. These materials may be subdivided as (a) natural agents of control, such as insect predators, bacteria, and viruses; (b) herbicides; and (c) pesticides. Ecosystem concern focuses on the occurrence, transport, concentration, and effect of biocides within a watershed from source waters to near-shore waters. Regarding this concern, the Committee makes several specific research recommendations.

(2) *Bacillus thuringiensis* (Burges and Hussey, 1971; Cantwell, 1974) is presently being utilized as a biocide for insects of the *Lepidoptera* group. We need to know if this bacterium is surviving and being concentrated in the aquatic ecosystem. If concentrated, where does it occur? Is it possible for *B. thuringiensis* to exchange DNA with the closely related *B. anthracis*? And if this exchange does occur, does it pose a serious public health risk?

(3) Herbicides are widely used to control weeds and other plants that interfere with cash crop operations on agricultural lands (Anderson, 1977). We need to know if herbicides or the by-products of these compounds move into the aquatic ecosystem. How are these compounds transported within the aquatic environment? What effect(s) do they have on the primary producers

(phytosynthetic organisms) in the aquatic environment? And how are the possible effects on primary producers translated into more direct effects on man and his activities? (For example, how do they affect the shellfish industry and the growth and development of commercially important fish in the near-shore environment?)

(4) Pesticides are widely used in the terrestrial environment. A good deal of information has been collected on the occurrence, transport, concentration (for example, at different trophic levels), and effects of these pesticides. But we must continue to monitor pesticides, especially the new types. In addition, we must make an effort to predict the behavior of pesticides as general classes of compounds in the aquatic environment (Stuper, et al., 1979).

Hormones and food additives from animal wastes. Animal wastes consist of concentrated organic and inorganic material that must be disposed of either by dispersal or recycling. Both disposal methods can generate significant problems for the aquatic ecosystem, perhaps the best documented problem being eutrophication. Less well documented problems are posed by the presence of drug and hormone residues and of food additives in animal wastes (Fontenot and Webb, 1975). Drug and food additive residues are present in animal waste if they have been administered in animal feed. These residues may include metals, antibiotics, arsenicals, nitrofurans, and hormones.

(5) Thus, we need to know the occurrence and concentration of such residues in animal wastes. We should learn how and to what extent such residues are metabolically altered *in vivo* or at the site of primary concentration and whether these residues contribute to the spread of drug-resistant pathogens.

Harvest wastes. By-products from the harvesting of agricultural and silvicultural crops can produce perturbations on adjacent aquatic ecosystems.

Some of the short-term immediate effects result from the large areas of living systems changing rapidly from a state of growth and assimilation to biodegradation and the accompanying release of organic by-products. Timing, physical location, season, harvesting technique, and many other factors can strongly influence the degree of impact this harvesting has on aquatic ecosystems. Investigations by Livingston (1978) and others reveal that clear-cutting in Southern river-bottom cypress forests can either strongly inhibit aquatic communities or, alternatively, have only a small effect, depending upon the techniques used during the tree harvest. Of course, siltation or erosional rates, leaf litter, and organic substances entering watersheds are all involved in both agricultural and forest culture practices. Additionally, slaughtering techniques, the use of plastics in certain truck crops, and the rapid release of chemical agents (biocides) from stems or crop by-products also become specific issues in selective practices.

(6) Current and experimental modes of harvesting could provide bases for research that compare the ecological events with the environmental risk-benefit considerations and thus evaluate aquatic ecosystem perturbations, the kinds and degrees of impact (the resiliency of the ecosystem), and the recovery prospects of ecosystems affected by these agricultural or silvicultural harvesting practices. Such research could lead to economic practices while mitigating adverse effects. The research should incorporate both laboratory studies of substances and biological effects, as well as field assessments of the ecosystems involved.

B. Municipal Wastes

Effluents, sludge, and septic tanks. The treatment of municipal wastewaters has not changed to any extent for many years. Nevertheless, the volume of water to be processed has greatly increased. Also new types and increased levels of toxic wastes now appear often in these wastes, and these toxic materials upset the biological systems counted upon to degrade the wastes. Finally, an ever-increasing amount of poorly biodegradable sludge is accumulating during waste treatment. The result of these trends is that the wastewater treatment systems often become overloaded and cannot effectively degrade the wastes. The toxic materials destroy biological effectiveness by altering or inactivating segments of the microbial population in the reactors. The reactor may or may not recover, depending on whether the microbes can become acclimated to the toxic materials. Thus, the effluent wastes are often improperly treated (or not treated at all) at the time of their entrance into bodies of water. This affects the watershed by adding both an organic and an inorganic load; at the same time, increased numbers of pathogenic microbes may find their way into the watershed. The sludges from the anaerobic digestors are added to land on the assumptions that (a) biodegradation will continue; (b) heavy metals will not accumulate in the soil; (c) the physical structure of the soil will not be affected; and (d) runoff waters from the land (or leachates) will not carry any of the residue into the local reservoirs or into ground waters. These assumptions have often been proven wrong.

Thus, it should be apparent that we need new, more effective, but totally different means of biological waste treatment. This treatment should be economically feasible. Field trials should validate that pathogenic microbes have not entered the associated natural bodies of water. And it would be nice if some use could be made of the energy destroyed through biodegradation, or if fermentation products of commercial value (like vitamin B_{12} or alcohol) could be generated. (The same view applies to the sludges.)

We also need research into the possibility of using wastewater, as clear effluent or effluent combined with sludge, in other constructive ways. Waste nutrients can stimulate plant production on uplands or in wetlands. If the production can be harvested and used, the nutrients are effectively reclaimed. In marine wetlands, the harvesting could perhaps occur through the natural food chain, leading to commercially useful fish. In a system in which the wetland stimulation promoted production of larval or juvenile fish in the marsh, which then mature in and are harvested from coastal waters, the potential for pathogen transmission from sewage to food would be greatly diminished.

We must also address the problems arising as a result of chlorination. It is possible, however, that a more efficient and reliable biological treatment system will some day reduce our dependence upon chlorination.

In the last few years, wastewaters high in fatty material (particularly from fast-food operations) have posed a new treatment problem. Thick layers of foam containing Nocardia bacteria are formed during aerobic treatment, and a pathogenic (to man) species of Nocardia has been detected among other Nocardia species in this foam. To date, we have found no reliable way to stop this Nocardia growth. Skimming it off and applying it to soil is not the answer.

Septic systems for handling wastewaters remain commonplace. In many instances, they function poorly, if at all, especially if the soil is not porous or the water table is high. Refining the present systems probably cannot improve the situation; thus, we badly need a new approach.

(7) We must develop new wastewater biological treatments incorporating principles not used in present systems. These treatments should be economically feasible, and could even yield fermentation products having economic value. These treatments should be able to handle overloads and pulses of toxic wastes.

(8) We must obtain better evaluations than we presently have available on the effects of sludges and wastewaters on soil, ground waters, and natural bodies of water. Included in this work should be field evaluations of the fate of those pathogens that may survive the treatment process.

(9) We must develop new and more effective methods for septic wastewater

treatment.

(10) We must develop biological control mechanisms (or process variations) to prevent Nocardia growth in aerated reactors.

Hyperchlorination treatment of municipal sludge (patented as the Purifax Treatment System). This application of chlorination at high levels to oxidize all organic residue in municipal sludge chemically is rapidly being adopted in 80 or more cities throughout the United States. The theoretical advantages to this system include its ability to remove by oxidation the nutritive components of sludge while it is in a semi-aqueous form. Secondly, the white pasty product that results appears to be suitable for disposal in solid-waste land fills. The resulting by-product has a number of halogenated compounds (from 2 to 4 percent wet weight; from 25 to 35 percent dry weight) that have not yet been identified; nor has its biological activity, toxicity, or ecosystem fate been determined. The halogenated compounds probably include pesticide-like substances with the properties, and environmental persistence problems, characteristic of known "hard pesticides."

(11) Studies have recently demonstrated that large numbers of halogenated and toxic by-products result from chlorination in municipal treatment plants (Jolley, et al., 1978a, 1978b). These and other projects suggest that we should identify the chemical structure and biological activity of the resulting by-products to assess and monitor their activity in natural systems around proposed disposal sites. We should pay particular attention to the potential movement of the compounds into water tables or adjacent watersheds.

C. Industrial Effluents, By-Products, and Wastes

Biological approaches to industrial waste treatment. Patterns of handling and treating industrial by-products are in a state of rapid change. Thus, we need research to determine the results of this change upon aquatic ecosystem characteristics as part of an overall evaluation of treatment effectiveness and applicability. Certain kinds of waste products are potential sources of biological nutrition and should be evaluated for their potential application and utilization in the restoration of wetlands, aquatic, or estuarine ecosystems. Lagoons in saline ecosystems provide unexplored potential as aquaculture resources for brine shrimp (Artemia), prawn, shellfish, or fish production. We could, for example, use selected microorganisms to enhance the degradation of compounds considered undesirable in natural ecosystems, or the transformation of compounds into bio-stimulants useful in protein production.

(12) The Committee believes that our increasing volume of industrial effluent must be examined by cooperative research projects seeking productive ways to transform potential ecologically harmful by-products of specific chemical industries into usable protein for livestock, fisheries, and man.

Hazardous waste disposal. Such hazardous wastes as radio nuclides, toxic metals, and toxic organics pose a threat to the aquatic ecosystem through spills or ground water leaching from disposal sites. Disposal sites of recent origin should be continuously monitored. In addition, we should make an attempt to identify old disposal sites.

(13) We need an understanding of the mobility of hazardous wastes through ground water and into a watershed. How, for example, are such wastes transformed in the aquatic ecosystem? Are they concentrated through the food chain? And what are the effects of toxic wastes in a watershed?

Cooling and cooling tower waters. Recently, a potentially major health problem has become a real possibility. This health problem is associated with cooling towers and streams that receive warm-water effluents from heating plants. Legionella pneumophila, the bacterium that causes Legionnaires' Disease, was eventually isolated from these sources when an outbreak of the disease occurred (U.S. Public Health Service, 1978). We know little about the natural ecology of this bacterium. It may well be that it multiplies in soil, where it enters a resistant stage, and then it uses the water systems as a means of dispersal. We do know that this bacterium can survive indefinitely in fresh water.

(14) We must mount an intensive study of the natural ecology of the bacterium that causes Legionnaires' Disease, particularly as this ecology relates to the dispersal of the bacterium by cooling towers and the warm-water effluents from heating plants.

Thermal effluents. Thermal effluents arise through heat exchange into a cooler source water. Considerable documentation exists on the general effects of thermal effluents. Thus, the Committee directs attention to two specific research recommendations:

(15) We should determine whether thermal effluents provide a means for increasing the survival of human pathogens in aquatic ecosystems (perhaps by raising the temperature to nearer the optimum for pathogen growth). Does increased survival lead to increased risk of transmission of pathogens from the aquatic ecosystem to man?

(16) We should determine how thermal effluents may be used for the direct benefit of man (for example, for home heating, for enclosed aquaculture, and for greenhouse heating).

D. Transportation

Spills of toxic substances. The reporting systems for spills of oil and hazardous materials have been improved. These reports reveal that great quantities of otherwise controlled substances are frequently released by accidental spillage. Mechanisms exist for states and federal agencies to respond, to take health-protective measures, and rapidly to commence clean-up procedures. But because of the wide range of substances involved, the habitats potentially affected, and the response measures available, the best decisions for ecological health are not always made. Coastal and marine spills are operationally attacked by a diverse team under the review of the National Response Team, which helps to integrate agencies and needed resources. A particular spill may enlist the support of on-call scientific coordinators who assist in identifying critical environmental areas, locate endangered species and people, and provide the resources to assess ecological effects and damage. Inland, however, little of this coordinated planning and research has been accomplished. Therefore, a dangerous potential for serious watershed contamination remains. Several regional reports document these needs and catalogue the available research.

(17) The Committee suggests that a compilation of all available data and risk analysis should be conducted to delineate specific research needs in the areas of protection, clean-up, and possible restoration of toxic spills into aquatic ecosystems. This research, perhaps focusing on perturbation studies, could help test the effects upon and resiliency of specific environments. We need the data from such studies to guide decisions during the emergency stages, and subsequently to assess the effects and measures taken to enhance restoration.

Transportation routes. The construction and maintenance of transportation routes on land--roads, airports and bridges--or on water--principally, dredging--exert an important impact on aquatic systems. Two important research issues arise here:

(18) We should know the extent to which construction related to transportation has disrupted our aquatic systems.

(19) We should be able to anticipate the harmful consequences of dredging contaminated sediments and how they can be minimized.

The first area of inquiry would address those wetlands absolutely destroyed by construction, and also the extent of the damaging disruptions.

How, for example, have bridges and culverts modified flow characteristics? How does channelizing and shortening rivers affect such riverine processes as self-cleansing? How does the distribution of paving in cities and towns affect infiltration, the distribution of water in soils, and the quality of ground water and runoff?

The second area of inquiry arises, particularly, in connection with the maintenance dredging in such places as the James River in Virginia, which is contaminated with Kepone, the Hudson River, partly contaminated with polychlorinated-Biphenlys (PCBs), and those estuaries and harbors contaminated with petroleum hydrocarbons. In some cases, perhaps, dredging spoils could be dumped on the continental shelf and covered with enough clean sediment to prevent pollution damage. But first we must learn whether or not those pollutants would leach into the water. And we must assess the probability that animal burrowing, feeding, or the pumping of water through sediments during respiration would release different sorts of chemicals. The disposal of dredging spoils on land risks conveying these chemicals into the ground water, perhaps slowly over long periods, which would permit their re-concentration elsewhere--perhaps in those animals that live where the ground water eventually reaches the land surface or flows into a body of water.

(20) Thus, the Committee recommends research on both past and potential damage to wetlands visited by construction activities associated with transportation. An assessment of the present extent of the damaged wetlands would be valuable for both restoration purposes and to guard against future impact. The safe disposal of dangerous dredge spoils is an essential activity; thus, we should encourage research on the biogeochemistry of the pollutants in any suggested disposal site.

E. Resiliency of Aquatic Ecosystems

Generally speaking, natural ecosystems exhibit a considerable amount of resiliency, but there are finite limits to this resiliency. One of the major unsolved problems is not only how to define the resiliency of an aquatic ecosystem, but also to document early warning signs of irreversible damage.

(21) Thus, the Committee suggests that the general biological indicators of the normal functioning of aquatic systems should be delineated for aquatic ecosystems on a regional basis. Moreover, field perturbation studies should be designed and carried out for testing the hypotheses that this research advances.

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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University
and
The U.S. Environmental Protection Agency

The Atmosphere As a Critical Ecosystem

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THE ATMOSPHERE AS A CRITICAL ECOSYSTEM

I. Introduction

Ultimately, the interest and concern expressed about various air pollutants arises because of their potentially deleterious effects on various living things. Air pollutants may affect human health adversely, either directly or indirectly, and in either acute or chronic ways. Pollutants may harm the structure and functioning of natural and agricultural ecosystems, and they may accelerate the decomposition of man-made materials, buildings, and artifacts (for example, statues). In addition, some pollutants exert unpleasant esthetic effects, like the odors from reduced sulfur compounds and certain organic substances, and reduced visibility attributable to primary and secondary aerosols. Finally, many pollutants can affect all three classes of receptors: human health, ecosystems, and materials.

Many important questions about the effects of various air pollutants on receptors have yet to be answered. For example, quantitative risk assessments remain to be established for chronic effects many trace pollutants have on human health. The synergistic effects of simultaneous exposure to several pollutants remain largely unexplored. The long-term effects of acid precipitation on aquatic and terrestrial ecosystems need to be identified and quantified, and numerous other examples of information gaps on the effects of air pollutants exist.

Many of these topics have been addressed in detail by other Committees, while the scope of this Committee's research recommendations is limited primarily to the processes that precede the effect of pollutants on receptors (that is, emission rates, transport and transformation, and deposition).

Pollution affects not only those near the source, but as industrial centers continue to grow and emit more pollutants from tall stacks, people and ecosystems hundreds and perhaps thousands of kilometers downwind as well. Thus pollution has become an interstate or international problem. While we have justifiably paid a good deal of attention to the study of pollution near the source and many validated models exist as a result, only recently have we begun to study regional-scale problems extensively. Compared to our understanding of local pollution problems, our understanding of regional transport and diffusion processes and chemical transformation over long periods, and over large horizontal and vertical distances, is limited. The Committee recommends, therefore, that the Environmental Protection Agency accord regional air quality problems the highest priority. The Committee has, however, identified some important local problems that deserve the EPA's continued support or new initiatives.

A. The Fate of Pollutants

The ultimate interest in a particular pollutant is its effect on receptors, or, more generally, the effect on the entire ecosystem. That effect depends on the concentration of the pollutant at the receptor and the length of exposure. These variables are products of a conceptually simple chain of events: (a) emissions (natural and anthropogenic); (b) transport and diffusion (vertical and horizontal); (c) transformation (chemical reactions); and (d) removal. It may be easy to list the components of a pollution chain, but each link may be enormously complicated and difficult to measure or model accurately. The degree of difficulty varies greatly from one pollutant to another, although almost all pollutants are transported by the wind in the same way.

An understanding or prediction of air quality at a receptor depends on the accuracy of the emissions inventory, and inventorying anthropogenic emissions can be a major economic problem. This problem may be partially solved some day by remote sensing techniques. In addition, natural sources along the trajectory may be signfiicant for the long-range transport of such pollutants as sulfur. These natural emissions need to be better understood and incorporated into air quality models on regional and larger scales.

From the time a pollutant enters the atmosphere, it is transported downwind and diluted by vertical and horizontal mixing. When they are present, cumulus clouds are particularly important in the vertical mixing process. Some compounds (gases and aerosols) interact chemically with other constituents as they move along with the wind. Over regional scales, the variability of meteorological phenomena, including the three-dimensional wind, vertical temperature structure, humidity, precipitation, and incident shortwave radiation, become more influential than they are in localized air quality problems, and research should be continued on regional meteological models. Not only is the vertical and horizontal transport more complicated, but the longer period of travel also permits more chemical and photochemical reactions to occur and introduces additional, different chemical and photochemical reactions. Thus, air chemistry becomes crucial to an understanding of regional air quality, and the Committee, therefore, recommends a continuing major research effort in this area.

Such removal processes as dry and wet deposition, precipitation scavenging, and radioactive decay are atmospheric cleansing mechanisms that become increasingly important over large areas and long periods. Small errors in removal rates when integrated over a long time may produce significant errors in concentration at a receptor. Furthermore, the removal processes depend on meteorological phenomena, especially clouds and precipitation, as well as the type of surface in contact with the pollutant. In general, the Committee recommends continued research into the removal rates of specific pollutants.

B. Air Quality Models

Air quality models range in complexity from simple conceptual models to complicated three-dimensional numerical models. The uses of air quality models include (a) predictions for use in the air pollution control strategies, for example in the intermittent burning of "clean" and "dirty" fuels, depending on the meteorological conditions; (b) land use studies, including environmental impact studies; (c) analyses of particular air pollution episodes; (d) evaluation of the effectiveness of a particular control strategy; (e) simulation of proposed field programs; and (f) theoretical studies of pollution transport, transformation, and removal.

A general air quality model may often be divided into two major components: a meteorological model, and an air chemistry model. It is often possible to neglect the effect of pollutants on the atmosphere over periods of about a day. In this case, the meteorological model may be run first to produce the meteorological parameters necessary for the chemistry model. Given the three-dimensional winds, stability, moisture percentages, and radiation, the pollutant model evaluates the transport, chemical transformation, and prospects of pollutant removal. While the number and complexity of the chemical reactions vary greatly from one pollutant to another, many pollutants require precisely the same meteorological input.

Because of the difficulties in resolving the variability of atmospheric variables and pollution concentrations over the regional scale, few complete data sets exist and model validation on this scale is in its infancy. Nevertheless, the potential uses to which regional scale air quality models can be put warrant their continued development. Attention should be given to the design of a comprehensive validation experiment as well as to a review and careful analysis of existing and future data sets. In such a design it is important to consider the spatial and temporal resolution of meteorological and chemical components necessary for an adequate representation of each portion of the pollution chain. The Committee strongly urges cooperation among the various groups in the design and execution of major field programs.

II. Recommendations

The Committee on the Atmosphere as a Critical Ecosystem has grouped its recommendations under six subdivisions, lettered A through F. The actual recommendations have been numbered sequentially, 1 through 18, throughout the balance of this Report.

A. Regional Scale Processes

Recent studies of the temporal and spatial patterns of pollutant concentrations and of attendant meteorology have established that the causes of air pollution problems in a locality may not be confined within the vicinity of the afflicted locality; rather, they often arise from sources and processes that have a regional, a hundreds-of-kilometers, or perhaps a thousands-of-kilometers dimension. Thus, direct observations of pollutant transport and studies of air movement within high-pressure meteorological systems have shown that pollutant transport may cause elevated O_3 concentrations several hundred kilometers downwind from the source area and elevated sulfate and aerosol concentrations much farther downwind than that. This finding is extremely significant from a control standpoint, in that it dictates that effective control strategies must be designed for and applied upon the entire source area affecting a receptor locality. Thus, the need to develop regional models is established and imperative. Two main questions arise next: (1) What is the optimum scale to be used in a regional model? (2) Can a model developed for (let us say) the northeast corridor be applied to other regions?

The first question cannot yet be answered, mostly because the maximum scale of transport has not been determined for the various pollutants. This gap reflects inadequate information on the various transport pathways, especially on pollutant transport occurring in the middle troposphere above the mixing layer.

(1) Such information must be obtained--especially for the photochemically less reactive pollutants--and be used in concert with relevant meteorological and topographic data to divide the continental U.S. into an appropriate number of model regions.

Nor can the second question be answered unequivocally at this time, although there are indications that models derived and validated for a given locality or region are not universally valid.

(2) The EPA must investigate the accuracy of both the urban models and the regional models when applied in different locations or regions and, if necessary, proceed with the development of region-specific models.

B. Oxidants

Beyond justifying the O_3 air quality standard as conducive to health, the current situation and priorities regarding the ozone-oxidant problem are as follows: Emission inventories appropriate for model application are expensive to obtain, difficult to extract from emitters, and, in the case of natural emissions, speculative at best. The last problem is particularly intractable in the case of regional models because of the relatively greater importance of natural emissions within large regions. Modeling the dispersion process occasions the same problems for ozone as for the other photochemical pollutants, and as already noted, it requires additional information on pollutant transport pathways. The uniqueness of the ozone-oxidant problem is that ozone formation and ozone destruction processes occur simultaneously but with widely varying relative rates. This fact introduces enormous complexities that make the validation of ozone models both imperative and extremely difficult.

(3) Thus, the EPA should spend significant effort on validating ozone models intensively and extensively--that is, under a variety of conditions

in each locality or region and, perhaps more importantly, in a variety of localities or regions.

(4) Another need is for research devoted to modeling photochemical pollutants other than ozone, peroxyacetyl nitrates (PANs), nitric and other acids, aldehydes, and peroxy compounds. The specific effort needed here is for further reaction mechanism studies and for field validations of the resultant models.

C. Acid Rain

The acidic character of rainfall is steadily eliminating life in lakes in many parts of the world, especially in the eastern U.S. The productivity of forest and other terrestrial ecosystems is also being reduced through changing soil properties caused by acid rain.

The acidic components of rain are predominantly sulfuric and nitric acid. The sources of the sulfuric acid are largely fossil fuel power plants and smelters, perhaps up to thousands of miles distant. The power plants emit SO_2, which is transformed to sulfate during atmospheric transport. The transformation processes and rates are not well understood. NO_x is converted to nitric acid via complicated photochemical mechanisms. Important sources of NO_x include mobile sources (automobiles) and stationary sources (power plants, home heating, and industry).

(5) We need research on the production of acid rain and, more specifically, on the atmospheric transport and transformation processes and rates, including transformation dynamics within and outside of clouds, transformation rates, seasonal reaction differences, the effect of atmospheric ammonia and other bases on buffering and increasing rates of conversion, and the effect of aerosols and gases on acidity. Ultimately, we must develop models relating rates of emissions of SO_2 and NO_x to the acidity of rainfall downwind.

(6) We need research that characterizes the properties of acid rain geographically and seasonally and along transport pathways onto soils and

vegetation and into waters, as well as the changes, correlated with the duration of the acidity, of lakes and soils.

(7) Monitoring should be conducted at selected representative sites to measure these properties.

(8) We need research that connects acid rainfall with the sources of those emissions capable of being transformed into acid rain.

(9) A solution to abating acid rain, now of interregional and international importance, from the technological viewpoint appears straightforward. Sulfur oxide and nitrogen oxide emissions should be abated, because once they enter the atmosphere, they cannot be scavenged before they eventually cause damage. We do, however, need control technology research to develop practical methods for desulfurizing fossil fuels prior to combustion or removing the sulfur oxides prior to emissions. Similarly, economic methods of decreasing NO_x emissions need to be pursued. Methods of mitigating the deleterious effects of acid rain on ecosystems should certainly be developed.

(10) The EPA should conduct an integrated impact assessment, including the socio-economic aspects of effects and controls.

D. Aerosols

Atmospheric particles affect the transparency, the radiation balance, and the temperature structure of the atmosphere. They are also involved in the formation and evolution of clouds and may affect human health.

The particle sources are both natural and anthropogenic. On a global scale, particles from such natural sources as sea salt spray, rock and soil debris, volcano emissions, and forest fires, outnumber by far the man-made particles from power plants, paper mills, and smelters. On the other hand, on local or regional scales (near cities and industrial parks), the contrary is often the case.

Present estimates of natural aerosol particle emission rates are based on a small amount of data gathered in specific regions. Better knowledge is available on man-made particles, but only for the total emission; less information is available about the size distribution and chemical composition of both natural and man-made aerosol particles.

Because each area concerns a particular size range--for example, only particles smaller than 1 µm can reach the lung (Natush & Wallace, 1974) while particles in the size range of from 0.3 to 0.7 µm affect atmospheric visibility--the Committee recommends that research be devoted to the study of the size distribution and chemical composition of natural and anthropogenic aerosol particles.

Particles are also produced as a result of gas reactions in the atmosphere. But estimates of the rates at which these reactions produce particles are even more difficult to make because of the many types of reactions and chemical species involved.

As particles are transported from the source, their number, concentration, size distribution, and chemical composition change continuously as a result of (a) chemical reactions; (b) the condensation of vapors, in particular water vapor; (c) coagulation; (d) the formation of new particles from gas reactions; (e) dry deposition; and (f) wet removal.

(11) Each of these processes is susceptible of further research. In particular we recommend studying

(a) the heterogeneous reaction mechanisms and reaction rates on solid particles;

(b) the modification of aerosol characteristics by chemical processes in non-precipitating clouds--for example, the formation of sulfate and nitrate aerosols by the oxidation of SO_2 and NO_x in cloud droplets;

(c) the deposition velocity of particles on surfaces of different characteristics; and

(d) the relationship between emissions and ambient concentrations.

E. Baseline Levels of Pollution

Future changes in air quality will reflect the composite of offsetting influences from emission growth and emission control. The net result cannot be predicted with any confidence since the air quality predictive models available have not and cannot be validated. To observe such changes directly and to provide the data required for model validation, one would have to initiate and sustain a long-term effort to establish baseline levels and monitor the changes in the pollutants of concern.

(12) The Committee specifically recommends, therefore, that the EPA initiate such an effort in areas relatively far from major emission sources and include, at the minimum, measurements of gaseous hydrocarbons, O_3, NO, NO_2, PAN, HNO_3, sulfate, SO_2, aerosols, toxic organics and inorganics, trace metals, precipitation acidity, NH_3, and N_2O.

(13) The Committee also recommends the monitoring of concentrations of OH radicals to assess the levels of and trends in the cleansing power of the atmosphere. An obvious and unavoidable part of this effort should be directed to the development of the instrumentation and procedures needed to perform the requisite analytical measurements.

F. Additional Problems

Whereas some of the major unsolved problems involve regional pollution, practical applications frequently involve "local pollution," which is to say pollution within a radius of 10 kilometers of a power plant. Environmental impact statements require models on this scale.

(14) Local dispersion. Certain factors needed for predicting local concentrations are poorly understood. This is particularly true for vertical dispersion from an elevated source. Here, we need measurements of the vertical distribution of contaminants near sources with known emission rates (that is to say, tracer studies). By contrast, lateral dispersion is relatively well understood.

Other problems involve special studies of nighttime dispersion, especially on clear nights in light wind. Here, the pollutants disperse in a fanlike manner; in the morning (sometimes earlier), vertical turbulence begins and brings large concentrations to the surface. To estimate these concentrations (fumigation) we have to estimate the nighttime lateral dispersion more accurately than is presently possible. The Committee recommends that this process be studied in field experiments.

(15) The effects of the heat and water vapor released from large power plants do not seem to be important on a regional or long-range scale. On a local scale at distances on the order of a few kilometers the pollution introduced is of certain concern. The following effects have been observed (Kramer, et al., 1975):

(a) sun shadowing by wet plumes and a consequent reduction of solar energy at the ground;

(b) fog caused by the increase of RH near the ground, which extends for a few hundred meters;

(c) change in cloud coverage and frequency of precipitation, and a greater frequency of cloud formation and eventually precipitation at distances within 1 kilometer downwind. (We need to study more thoroughly the effects of meteorological conditions on plume and fog formation around individual plants.);

(d) icing on nearby trees and structures, and a greater frequency of icing on trees and buildings downwind of the plant;

(e) interaction of stack and wet plumes in fossil fuel operated plants with modification of the aerosol population. (We need more research to determine reaction rates under conditions of high relative humidity.);

(f) drift deposition up to distances of 2 or 3 kilometers. This deposition is serious when ocean or contaminated water is used for cooling purposes. Only few observations of drift depositions around power plants are available; more are needed in order to validate the existing models. (See, for example, Policaster, et al., 1979.)

(16) Toxic substances. Atmospheric pathways are important sources of such toxic substances as trace organics and heavy metals deposited on land and water surfaces. In environments remote from industrial activity, the atmosphere

may, in fact, represent the major source of these substances. For example, atmospheric deposition is the major source of polychlorinated biphenyls (PCBs) in Lake Superior. Three deposition mechanisms link the atmosphere with land and water: (1) precipitation in rain and snow, (2) dry fall of particulates (aerosols), and (3) direct absorption of gaseous pollutants. The quantitative importance of each of these mechanisms and of the total atmospheric loading of refractory organics and heavy metals should be determined on a regional basis. In addition, the organic composition of rainfall needs to be evaluated at selected sites across the country. Rates of transport and transformation of specific classes of refractory organics from emission sources should be evaluated so that ranges of transport and atmospheric residence times can be established. Research should be conducted on the speciation of refractory organics in the atmosphere. (For example, are they present as vapor or sorbed onto aerosols; if the latter is the case, what is the composition and size distribution of the aerosol particles?) Rates and efficiencies of the scavenging of both organics and metals by rainfall should continue to be investigated. Finally, research should be conducted on the transformation of trace organics emitted by anthropogenic sources into new (and potentially toxic) substances by photochemical reactions in the atmosphere.

(17) Impact of new energy technologies. The principal impact on the atmosphere of such new energy technologies (NET's) as coal and oil shale utilization involves emissions and their transport through the atmosphere. The issue here centers on the chemical composition, emission quantities, and the form of the emission (aerosol, gaseous, or particulate).

Research should be conducted to identify NET's, to characterize (potential) emissions, and to study the transport, transformation and fate of these emissions with an eye toward (a) an early warning evaluation of the potential impact or acceptability of the NET, (b) feedback to NET developers concerning potential pollution problems, and (c) a comparison of environmental NET impact with the technologies they are intended to replace.

G. Global Problems

(17) Stratospheric ozone. Stratospheric ozone prevents a large fraction of ultraviolet solar radiation from reaching the ground. Since this radiation is harmful to humans, other animals, and plants, a substantial depletion of this ozone is to be avoided. Ozone changes could also affect the surface climate, although this effect now appears to be small, at least in comparison to changes produced by increasing CO_2. Ozone can be destroyed through catalytic reactions involving compounds of hydrogen, nitrogen, and chlorine. Of these, no significant effects involving hydrogen have thus far been identified.

Chlorine compounds attributable to human activity have been measured in the stratosphere, and this load is likely to increase. So far, the most damaging source of chlorine appears to be fluorocarbons ("Freons"). Freons 11 and 12 appear to constitute a threat; their continued emission at the present rate could lead to an eventual decrease of ozone by some 15 percent. This decrease would be smaller if a sink for chloro-fluoro-methanes (CFMs) in the troposphere could be identified and tested. So far, no credible sink has been suggested; accordingly, the Committee recommends a continued search for tropospheric sinks.

A substitute for Freons 11 and 12 for some purposes is Freon 22, but this compound reacts with OH radicals in the troposphere. If there is enough OH, Freon 22 will constitute no threat to the stratosphere. But the Committee recommends a thorough program of measurement and analysis of atmospheric OH concentrations and research to predict its future levels. The same recommendation can be substantiated for another reason: The use of methyl chloroform as an industrial cleaner and degreaser is increasing at the rate of more than 20 percent a year and is expected to contribute significantly to stratospheric ozone depletion. If sufficient OH exists in the troposphere, the chlorine in methyl chloroform will pose only a small threat to stratospheric ozone; if not, control of this compound may have to be considered.

The threat to stratospheric ozone posed by the nitrogen compounds NO and NO_2 emitted by supersonic transports (SSTs) is no longer thought to be as serious as it was only a few years ago, due to recently revised rate constants.

Still, the proliferation of nitrogen fertilizers and widespread forest cutting may add significant amounts of such nitrogen compounds as N_2O to the troposphere. It is not clear just how improtant sinks for this gas are. Eventually, though, N_2O can react with excited atomic oxygen to form two NO molecules, which can then attack the stratospheric ozone. This chain of reactions involves many poorly understood processes and rates which should certainly be studied: The EPA should undertake to identify and quantify N_2O sources (anthropogenic and natural) and their rates of emission into the atmosphere. Is (for example) the oceanic source much larger than the anthropogenic source (which would imply strong tropospheric sinks)?

(18) Carbon dioxide. The carbon dioxide concentration in the atmosphere is around 330 ppm. It has been increasing throughout this century and is expected to reach 380 ppm by the year 2000 and possibly 600 ppm by the year 2025. This increase represents only about half of the CO_2 emitted into the atmosphere by burning fossil fuels. It is not clear where the other half goes, but presumably it disappears into the oceans. Forest cutting may add additional CO_2, which must also be entering the oceans.

Complex climate models have been used to study the characteristics of an atmosphere with approximately twice the CO_2 it now contains. Because CO_2 is transparent to visible light, but an efficient absorber and emitter of infrared light (15 micrometers), it transmits sunlight but partially absorbs infrared radiation from the ground and re-emits it toward the ground, thus warming the air close to the surface. Simultaneously, it cools the stratosphere. The best published models suggest that the doubling of CO_2 will produce average global surface warming of from 2 to 3° C and a high-latitude surface warming of about 9° C. This effect would constitute a serious climate change, implying (for example) the dislocation of agriculture, significant melting of ice, and a sea level several meters higher than the present level.

These models, however, make simplifications and leave out potentially important feedback. Whether the net effect of this feedback is positive or negative is not known.

The study of the effect of climatic change due to increased CO_2 must be one of the most important aspects of any climate program and will almost certainly receive a great deal of deserved attention in many government agencies. The EPA should, therefore, initiate research on

(a) an integrated impact assessment as an early warning tool for decision making;

(b) an evaluation of water supply quantity and quality under various climatic conditions and use requirements (for example, the Agency should consider drinking water treatment technologies for removing increased nitrates in water supplies caused by an increased use of fertilizer to overcome reductions in agricultural productivity caused by climate changes);

(c) assessing the state of the technology designed to prevent or reduce CO_2 emissions from fossil fuel plants into the atmosphere; and

(d) the sensitivity, resilience, and survivability of ecosystems and organisms facing such annual extremes of climate variability as winter cold and summer drought.

The Committee recognizes that climate dynamics studies, including the biogeochemical cycle of carbon, have been undertaken and supported by other agencies. The studies recommended here would, however, use and supplement the data acquired by these other agencies.

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Reports of Meetings
Held on June 26 and 27, 1979

To Develop Responses
to Questions Raised by the
U.S. Environmental Protection Agency

REPORT OF GROUP 1

ENVIRONMENTAL PROCESSES; MANAGEMENT-CONSERVATION

Prepared in Response to Questions from the
U.S. Environmental Protection Agency

Questions

Environmental Management

1. Microcosms

It would be helpful if the panels would provide some insights into areas in which microcosms research might provide useful results. For example, do the panels feel that microcosms can be used to predict expected effects in the real world environment? Alternatively, what scales of microcosms might we best carry out research on? What particular ecosystems might benefit from research on microcosms?
(This question is also asked of Environmental Impact and Ecosystem Restoration panels.)

Environmental Impact

1. Microcosms

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(This question is also asked of Environmental Management and Ecosystems Restoration panels.)

2. Biogeochemical cycles

Much discussion has been given to our lack of knowledge about the ultimate transport and fate of metals through biogeochemical cycles. In developing initiatives, it would be helpful to identify some chemicals or compounds that might be investigated with respect to their cycles. In addition, it would be helpful if the panels could provide some direction regarding how such investigations might be carried out.
(This question is also asked of How, What, Where - In What Form panel.)

3. Environmental impact statement evaluation

The panel recommends that EPA carry out research to assess the success with which Environmental Impact Statements have predicted impacts of actual changes in the environment. If this recommendation is motivated by some particular instances where EIS's have failed, that particular information would be helpful in terms of developing our initiative. Also helpful, however, would be simply the identification of some particular facilities for which the panel thinks the EIS process has been noticeably deficient.

Ecosystem Restoration

1. Methods to better measure and define the state of ecological systems

Here it would be helpful if the panels could provide elaboration on what features or measurement techniques would be helpful in achieving this goal. Particularly useful would be references to work that has either been successful or indicated potential for success in developing such measures. In addition, it would be helpful if the panels would recommend specific ecosystems which should be examined.
(This question is also asked of How, What, Where - In What Form panel.)

2. Threshold and recovery in ecosystems

The concept of threshold populations below which observable changes in ecosystems population and diversity occur has been recommended as an area of research. Suggestions along the lines of how this threshold concept would be pursued as a research objective would be helpful. For example, the panels might identify work that has already been done in this area or some ecosystems that would be susceptible to this type of investigation. With respect to recovery, we would also benefit from reference to task studies or from recommendations for the specific types of ecosystems that might be amenable to study.
(This question is also asked of How, What, Where - In What Form panel.)

3. Restoration of ecosystems

Elaboration of this concept would also be helpful. We are aware of the restoration of wetlands work which has been carried out by the Corps of Engineers. Similarly, restoration of species has occurred in some of the anadromous fishery in the U.S. We would benefit greatly if some of the methodology for carrying out such restoration research could be described by the panel.

4. Microcosms

It would be helpful if the panel would provide some insights into areas in which microcosms research might provide useful results. For example, do the panels feel that microcosms can be used to predict expected effects in the real world environment? Alternatively, what scales of microcosms might we best carry out research on? What particular ecosystems might benefit from research on microcosms?
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How, What, Where - In What Form

1. Methods to better measure and define the state of ecological systems

Here it would be helpful if the panel could provide elaboration on what

features or measurement techniques would be helpful in achieving this goal. Particularly useful would be references to work that has either been successful or indicated potential for success in developing such measures. In addition, it would be helpful if the panels would recommend specific ecosystems which should be examined.
(This question is also asked of Ecosystem Restoration panel.)

2. Methods to measure stress in particular ecosystems

Here again elaboration by the panel would be helpful including identification of the types of stresses and types of critical ecosystems stressed. In addition, suggestions dealing with the kinds of measures which should be developed in order to assess stressing impacts would be most helpful.

3. Threshold and recovery in ecosystems

The concept of threshold populations below which observable changes in ecosystems population and diversity occur has been recommended as an area of research. Suggestions along the line of how this threshold concept would be pursued as a research objective would be helpful. For example, the panels might identify work that has already been done in this area or some ecosystems that would be susceptible to this type of investigation. With respect to recovery, we would also benefit from reference to task studies or from recommendations for the specific types of ecosystems that might be amenable to study.
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4. Biogeochemical cycles

Much discussion has been given to our lack of knowledge about the ultimate transport and fate of metals through biogeochemical cycles. In developing initiatives, it would be helpful to identify some chemicals or compounds that might be investigated with respect to their cycles. In addition, it would be helpful if the panel could provide some direction regarding how such investigations might be carried out.
(This question is also asked of Environmental Impact panel.)

5. Acid rain

EPA already has a relatively short term acid rain research program. The recommendations of these panels, however, relate to the longer term studies which will be required in order to improve significantly our understanding of the degradation problem with respect to soils. Further discussions which specify a particular kind of research effort would be most helpful.
(This question is also asked of Critical Ecosystems - Atmosphere.)

Critical Ecosystems - Land

1. Biomonitoring

Here it would be helpful to know if the panels are referring to biomonitoring for the purposes of indicating effects in ecosystem populations or diversity or whether they are referring to biomonitoring used primarily for indicating the presence of pollutants in particular environments. Helpful here also would be the reference to particular species that have

been used successfully in biomonitoring and the types of ecosystems for which biomonitoring shows the greatest promise of success. Ideas regarding how a biomonitoring system might be structured would also be helpful (i.e., what composition of species might be included in monitoring a particular ecosystem). The panels might also attempt to design a research program that could have as its end product methods to design adequate biomonitoring systems.
(This question is also asked of Critical Ecosystems - Water.)

2. Soil systems

The panel recommends research in the area of processes of degradation, transformation and transport that occur in the soils medium. It would be helpful if they could identify particular problems which endanger the viability of certain soils systems, e.g., contamination by pesticides or contamination by acid rain. It would also be helpful if they would specify whether laboratory, field or survey type studies would be the best way to address these problems.

Critical Ecosystems - Water

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(This question is also asked of Critical Ecosystems - Land.)

2. Nutrient dynamics

Much research has already been conducted in the area of nutrient dynamics. It would be helpful if the panel would specify those particular aspects of the nutrient problem which have not been adequately studied.

Critical Ecosystems - Atmosphere

1. EPA already has a relatively short term acid rain research program. The recommendations of these panels, however, relate to the longer term studies which will be required in order to improve significantly our understanding of the degradation problem with respect to soils. Further discussions which specify a particular kind of research effort would be most helpful.
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COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University

and

The Environmental Protection Agency

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We have considered all of the questions raised by the EPA, and believe we have responded to the sense of each. Our answers, however, are consolidated into a somewhat smaller number of groupings than the original questions.

The Study of Microcosms and Other Controlled Systems

Field measurements and observations are time consuming and difficult. Field experiments are, moreover, sometimes impossible to conduct. Controlled studies in simplified, artificial microcosms or, where feasible, controlled parts of natural systems, may help elucidate certain ecosystem situations. They have been used successfully in laboratory studies of pesticide distribution and degradation in soil-aquatic and plant-animal systems.

Air pollution phytotoxicologists have effectively used "open top" chambers as a microcosm to demonstrate that ambient air pollutants can reduce the yield of agriculturally important crops. When plants were grown in chambers receiving primarily charcoal-filtered air, yields were higher than when plants were grown in chambers receiving ambient or nonfiltered air. This microcosm has been used with a diversity of crops including potatoes, snap beans, corn, and grapes. Despite problems associated with any modification of the ambient environment--for example, elevated temperature, subsidence of ambient air, etc., this microcosm has provided valuable data more representative of the real world than growth chamber or greenhouse experiments.

At the Gulf Breeze Laboratory, a predatory fish has been used to measure the subtle behavioral effects of pollutants on grass shrimp in a simple sand-water-turtle grass system; though the treated grass shrimp appeared to behave normally, they were much more susceptible to predation than the untreated grass shrimp.

An example of a simple controlled experiment involving a microcosm was the fencing off of a small plot of land in the Sahel Desert of North Africa. This simple barrier to grazing animals allowed the overgrazed desert vegetation recover remarkably fast, and the contrast between the dark vegetation of the fenced-in plot and the surrounding desert was visible even from satellites.

Bacteria, algae, and zooplankton (or protozoans) have been used successfully to indicate the controlling effect of a predator on a simplified food chain. The relative simplicity and low cost invite both replication and additional studies of the effects of changes in one or several variables in the experiments.

Thus, the Committee believes that a systematic exploration of microcosms and other controlled systems to establish the most appropriate conditions for and the limitations on the use of these tools in the assessment of environmental impact would be very valuable. Studies should be undertaken to utilize arrays of such systems to explore different aspects of the movement and alteration of single chemicals and combinations of chemicals under an expected range of environmental conditions. Verification through field studies must be part of these efforts to account for difficulties in simulating the complexity of (for example) macrofauna. The prediction of effects in the real world is unreliable unless such verification has been attained.

Ecosystem Persistence Limits for Recovery and Restoration Techniques

The purpose of restoring degraded ecosystems was clearly stated in the original draft: Some ecosystems should be maintained in a near-natural state as ecological refuges and others should be maintained at a stable but less-than-natural state, in order to provide goods and services for society. For some aquatic and terrestrial ecosystems, techniques are recognized for accomplishing successful restoration, but their relative effectiveness over a range of ecosystem types is poorly understood. Those involved in research into restoration techniques must develop a detailed knowledge of the fates and effects of each cause of degradation. We will need to know the rates of recovery and the limits of tolerance beyond which perturbed systems cannot recover to desired states--that is, persistence limits. This information must be coupled with a knowledge of the reversibility of the damage to those systems that have been disturbed.

Specifically, we must define the degree to which ecosystems can be displaced from equilibrium as a result of anthropogenic perturbants, while retaining the ability to recover once the perturbation is relaxed. If the perturbed states are reversible, we would say the system has not transcended a recovery limit. On the other hand, if the states are not recoverable to the original quasi-equilibrium, unperturbed state, then we would say a persistence limit has been transcended.

In addition (and irrespective of the ability to recover totally), it is essential to know, again from a management perspective, whether the recovery time is units, tens, or hundreds of years.

The existence of persistence units is exemplified by the extinction of the passenger pigeon, eutrophication of some lakes, and perhaps by a natural population of lake trout in Lake Michigan. The passenger pigeon fell rapidly from extremely large numbers to extinction despite significant attempts to maintain a viable population. Lake Trummen in Sweden became so degraded from receiving waste effluents for over 50 years that no improvement was seen in a 10-year period following diversion of wastewater from the lake. In Lake Michigan, at present and for the foreseeable future, lake trout are not reproducing because of high residues of PCB's and DDT. Physiological studies on lake trout support this tentative conclusion.

Such definitions of persistence limits and rates of recovery should be addressed directly and indirectly. Direct determinations of large scale natural ecosystem recovery limits are difficult for pragmatic considerations. However, there is at present a Clean Lakes Program within the EPA that supports the restoration of eutrophic lakes through the application of several in-lake techniques, including alum addition, dredging, aeration, dilution and flushing, hypolimnetic withdrawal, water level manipulation, and to some extent, macrophyte harvesting. The success of these techniques largely depends on the potential for controlling phosphorus cycling in the lake. Although efforts are underway on 73 lakes nationally, the effectiveness of the above-mentioned techniques is imprecisely understood. Research is needed for in-depth evaluation of these techniques over a range of lake types, particularly shallow lakes, as experimentally planned demonstration projects proceed. At present, restoration effectiveness cannot be predicted with sufficient reliability. Even less is known about lake recovery from heavy metal input. With a better understanding of recoverability and recovery rates, better estimates of cost tradeoffs can be made to deal with the question of wastewater treatment to prevent as well as restore water bodies now or in the future. To fill this void, experimental lakes should be established in the Great Lakes area to support long-term research into the recovery rates and capabilities of lakes subjected to such perturbations.

Other areas where we need more knowledge of recovery potential and restoration techniques include surface-mined land, the landscape surrounding smelters, and aquatic environments receiving metals. In some cases, recovery has been unacceptably slow. On the other hand, systems that flush rapidly tend to recover quickly once the perturbation is relieved. Examples include a number of streams like the Thames and Willamette Rivers, and lakes, especially Lake Washington in Washington State and Trummen in Sweden, once sediments were dredged. With our present knowledge, we cannot predict accurately enough which ecosystems will recover completely and rapidly and which will recover only incompletely and over a very long period of time.

We need indirect approaches to establishing ecosystem persistence limits because of the serious scalar limitations associated with direct field studies.

First, appropriate field experiments of large ecosystems are few and far between. Second, the definition of ecosystem persistence limits requires the application of different perturbants at combinations of different intensity and duration, with concomitant relaxation procedures. Such constraints clearly limit direct ecosystem manipulations.

Scalar reduction of large ecosystems, the so-called "microcosm method," may provide the experimental tool with which recovery limits for natural ecosystems can be established. We shall not pursue this point other than to say that microcosms can provide a system of reasonable size with which to perform the type of critical-limit experiments alluded to above.

Environmental Impact Statement Evaluation

The panel's recommendation "that the EPA carry out research to assess the success with which environmental impact statements (EIS's) have predicted the impact of actual changes in the environment" was motivated neither by prejudice nor current attitudes expressing dissatisfaction with EIS procedures. Such research is just a logically necessary ongoing evaluation procedure to assess the quality of EIS methodology and improve the effectiveness of EIS use.

Such an evaluation should attempt to answer the following sample questions:

(1) Did the EIS recognize all of the problems?

(2) Did the EIS correctly predict changes and other impacts?

(3) Did the EIS, based on knowledge available at that time, give rise to over- or under-engineering?

Evaluating the accuracy of EIS assessment techniques can help us develop and select control strategies. A sufficient number of EIS's have been completed, facilities placed in operation, and strategies implemented during the Council on Environmental Quality's (CEQ) and the EPA's lifetimes for us to start evaluating the validity of these impact predictions. Commonly used techniques could be evaluated on a prediction-versus-result basis. Information on the reliability and accuracy of the methodologies used in the EIS's would help the Agency's staff evaluate the adequacy of the EIS's they require. This research would also result in better environmental decision making.

This research would evaluate the tools used by the EPA in its EIS preparation activities and would subsequently help the Agency develop better tools for its EIS program. The methodologies developed by this research would substantially improve the Agency's ability to assess the enviornmental impact of various activities.

As another step in the EIS procedure evaluation, the EIS format should be re-evaluated with an eye toward making its writing and assessment more efficient.

Biogeochemical Cycles

Biogeochemical cycles warrant study because of potentially toxic transformations which occur naturally. Heavy, relatively non-toxic metals in elemental form become toxic when converted to organic form--for example, mercury to methyl mercury and nickel to nickel carbonyl. In organic form, heavy metals readily traverse the cell membrane and become potential health hazards. Examples of heavy metals worthy of study include lead, zinc, copper, nickel, arsenic, cadmium, beryllium, and chromium. Synthetic hydrocarbons--for example, PCB's and organochlorines--may be relatively non-hazardous until transformed in the environment; the hormonal effects of DDT transformed to DDD or DDE have been the subject of much attention. When carbon dioxide or nitrogen, sulfur, or phosphorus-based compounds enter the biogeochemical cycle, their impact may be detrimental. Problems like eutrophication, acid rainfall, or the greenhouse effect have been considered elsewhere. Consideration should be given to whether altered concentrations of these compounds might shift a given nutrient cycle so as to yield harmful products.

Biogeochemical cycles should be studied to determine whether pollutants may be bound at some point in the cycle to decrease their bioavailability. Research should be directed toward defining uptake rates, residence times in the various soils, plant and animal pools, and in the case of metals, the fraction of the metal that is readily regenerated in a soluble form that sediments from the water and (in turn) the fraction that is regenerated from the sediments. Whole watershed studies are desirable and should include the exchange among the atmospheric, aquatic, and terrestrial components. Mass balance models should be formulated on such systems, with the purpose of predicting concentrations in each component pool, and especially in the water.

Biomonitoring

The intent of the Critical Ecosystems--Land and Critical Ecosystems--Water panels was not to recommend a biomonitoring system but rather to recommend a long-term monitoring baseline study. It is difficult to assess the impact of increasing levels of a pollutant without monitoring changes in productivity or some other measure of plant (or ecosystem) growth. In the long run, we should monitor changes in carefully chosen ecosystem characteristics as a hedge against pollutant problems that we do not now understand or anticipate. Only by routine monitoring can we hope to alert ourselves to such new pollution problems as acid rain. Perhaps relatively undisturbed natural ecosystems in close proximity to urban and industrial centers would be good bets since deleterious effects ought to show up in these areas first. At the same time, though, as a basis for comparison, we should monitor selected, relatively pristine ecosystems remote from human influence. The document prepared by the Critical Ecosystems--Land panel suggests a general approach and general kinds of species to be considered.

While the intent of the two working panels was not to develop a biomonitoring program, there would be value in considering its uses. We can conceive of three possible kinds of biomonitoring:

(1) Bioassays, in which an organism is exposed to an environmental sample, and its response is used as a measure of the presence of a particular substance or condition. A familiar example is the canary in the coal mine; another example would be the survival of fish in live cars in an effluent stream.

(2) Biological indicators of present or past pollution episodes. Examples are the size, species diversity, and abundance of lichens as indicators of the presence of SO_2 or HF.

(3) The measurement of pollutant burdens in bioaccumulators. In a sense, the organism is used as the first step in the analytical process--that is, sample collection and concentration. Examples include mussel watches, duck-wing surveys for pesticide, and even FDA Market Basket analyses for pesticides (and other specific pollutants).

The uses of biomonitoring, as described above, will vary with the intent of the study and must be decided case by case. Thoughtful applications are essential to avoid misinterpretation--for example, fish in live cars may survive but be unable to reproduce, in which case an assumption of "no effect" would be erroneous.

Effect of Acid Precipitation on Soils

The effect of acid rain on soils, lakes, and rivers has been widely documented (see, for instance, Kramer, 1978). We need research in two areas: the meteorological and chemical processes that determine the spatial and temporal variation of acid rain, and the impact of acid rain on ecosystems in land and water.

Soils present yearly and seasonal variations, and short-term changes are often obscured by seasonal variations. It is, therefore, necessary to have long-term records of the chemical and biological quality of soils, as well as of the external factors (like acid rain) causing these changes.

The acidification of soils is caused not only by acid precipitation but also by the deposition of dry particles with absorbed SO_2, the dry deposition of acidic particulates, and the application of fertilizers that contain sulfur.

In order to establish to what degree each of these mechanisms contributes to the acidification of soils and surface waters, we need research in the following areas:

(1) the dry deposition of SO_2 on different natural surfaces;

(2) the chemical nature (acidity) of atmospheric particulates;

(3) the dry deposition of atmospheric particulates; and

(4) a determination of long-term variations in the spatial and temporal distribution of atmospheric aerosols and of the acidity of percipitation.

To achieve these objectives, we must maintain and expand the present precipitation sampling network and implement the network with measurements of particulates and dry deposition. We should establish the long-term (several years at least) variations in precipitation and particulate composition through the normal network operation. In addition, we should study the detailed variation in acid precipitation over individual episodes lasting a few hours to several days. In these studies we need high frequency (sequential) samples in order to identify and understand the temporal and spatial variations of the aerosols and precipitation under various meteorological conditions.

In addition to (and, if at all possible, in connection with) measurement studies of the long- and short-term variability of precipitation acidity, we should undertake field investigations of the response of soil and lake ecosystems at sites that experience heavy dosages of acid precipitation. These studies should seek to establish both the impact of precipitation with high concentrations of acid over short time periods and the long-term trends. Since many of the required measurements would be helpful to both studies, these field programs could also be combined with such other studies of soil systems as degradation by pesticides.

Selected sites should first be established in regions that experience the greatest acidity on a seasonal or episodic basis, in order to obtain a maximum signal-to-noise ratio. Studies of separate ecosystems should be established in areas of the country with pronounced differences in climate, soil types, and sensitivity of the soil and biota to acidic fluxes. As a minimum, sites in the Northeast, Mid-Atlantic states, Southeast, North Central states, and Far West should be included. The research must continue long enough to verify trends and evaluate short-term "noise." We should also conduct controlled, small-plot field studies in which the amount of acid influx can be varied artificially. Moreover, such studies should be conducted near to and simultaneously with the "natural" field program. The effect on various crops in the same experimental plot should be considered wherever practical. Analyses of the ecological response of soils should consider the effects of acidic fluxes on the mineral weathering processes and on the export of major cations (Na, Ca, K, Mg), trace metals (Fe, Mn, Cu, Co, Zn), and such other products of mineral weathering as silica and aluminum.

Aside from long-term measurements of mineral and nutrient fluxes, the studies should include (1) measurements of an ecosystem's primary production (net and gross), and (2) detailed studies (both lab and field). The effects of single acid rains on young shoots and leaves should also be examined.

In addition to the direct effects of acidity, bioactivity, and organism survival, acid rain may affect ecosystem productivity in at least two indirect ways, and research programs need to be established on both mechanisms and in both terrestrial and in aquatic ecosystems. First, acid precipitation may enhance the toxicity of various heavy metals like Cu, Cd, Pb, and Al. Both their concentrations and their biological availability are increased in acidic environments. Research efforts on heavy metals should involve both basic (for example, laboratory equilibrium) studies and field investigations to determine the extent of heavy metal buildup in acidified environments and the extent to which theoretical models of metal mobilization are applicable.

The second indirect effect of acid rain on ecosystem productivity concerns the inhibition of mineralization processes. Various lines of evidence indicate that microbial degradation of organic matter is less effective under acidic conditions. Thus, essential nutrients (especially nitrogen and phosphorus compounds) tend to remain tied up in organic detritus rather than becoming available for continued plant growth. Studies need to be undertaken on both terrestrial and aquatic ecosystems to establish the effects of acidification on all mechanisms of mineralization and nutrient recycling, including microbial (bacterial and fungal) degradation, predation by zooplankton and herbivorous fish, and consumption by other higher heterotrophs (for example, worms in soils).

We do not yet understand the mechanism of plant tissue damage nor do we even know if the pH within the plant changes during acid rain incidents. We, therefore, need detailed research into the mechanism of damage and the recovery mechanisms.

Response to the Questions on Measurement of Ecosystem State and Stress

A vast number of quantities defining state have been reported in the literature, including biomass, community diversity, productivity, nutrient regeneration rates, energy and carbon fluxes, and yield. All or none of these quantities may be useful indexes of ecosystem state.

The quantity to be measured should be based on biologically important features of the ecosystem. For example, yield might be most important in an agricultural ecosystem; productivity might be the feature of greatest importance in a natural ecosystem. A search for a universal indicator would probably be futile. But an approach that might be inexpensive and somewhat fruitful is suggested below:

> A number of ecosystem studies have been carried out where numerous variables and responses have been measured. These studies could be assembled and catalogued and common state variables compared, with the aim of isolating a few state variables that were sensitive to all perturbations. These variables could be used as assay quantities.

Candidate studies might include the International Biological Program (IBP) grassland biome project, Brookhaven Radiation Forest (see Woodwell, 1962), and the Hubbard Brook Experimental Watershed Program (see Likens, et al., 1977), and some of the coniferous forest biome work in Oregon and Washington.

In fresh water ecosystems the sewerage diversion experiment performed in Lake Washington (see Edmondson in Cairns, et al., 1977) as well as the above IBP projects--aquatic phases, immediately come to mind. In addition, the work done by the EPA in Lake Shagawa is also relevant, as well as the North American Project in eutrophication supported by EPA (1977).

Input (environmental) variables are likewise difficult to define. Again, the typical approach is to measure a plethora of quantities and attempt to relate observed changes in the state variables (if any) to these quantities by various statistical procedures. A universal procedure is probably impossible, but a general rule of thumb is suggested here:

> Organisms respond only to those environmental factors that are sensed or absorbed, or which interact in some way with the organism. Research designed to measure the response of given organisms to environmental factors must measure them in a way that is relevant to the organism.

As an illustration, consider the enormous effort in plant ecology and forestry to relate various ecosystem states to slope, aspect, and elevation. Plants do not sense these factors, but instead respond to temperature and light regimes. Likewise, the spruce budworm senses temperature and light differently, and its response is different. What is a meaningful environment to one organism is meaningless to another. The environmental metric chosen must be tailored to the species of interest.

Attempts to use this methodology have been going on for some years in Oregon (Waring & Cleary, 1967; Cleary & Waring, 1969; Zobel, et al., 1976). Levandowsky (1972) applies this approach in aquatic systems.

It is critical that the EPA not only define stress response but also support research on pollution tolerance. For example, if current crop varieties are susceptible to federally acceptable pollutant levels, research dollars should be spent to develop and understand genetically tolerant material. Research to support amelioration methods of forest ecosystems presently assaulted by acid rainfall is also in order.

Nutrient Dynamics

Watersheds are managed geomorphologically and hydrologically. They are not to a very great extent managed biologically. As a step toward biological management, this Committee feels that nutrient budgets should be developed for entire watersheds. For example, we recommend an overall budget for nitrogen.

The rationale for such a budget resides in the possibility that an increased nutrient load might be beneficial to an estuarine-salt marsh ecosystem; whereas such an increased load would probably be adverse to a lake. Basic to any management system is a knowledge of inputs and outputs.

Concluding Statement

Although the panel was not asked to discuss populations and associated problems, it is important for the EPA and the U.S. Government to realize and communicate to the public that the root of the pollution and energy problem is overpopulation. Increases in population will result in fewer resources per capita, higher prices per capita, and a further degradation of the standard of living and the environment. We see no way that the U.S. can meet its future energy needs without substantial shifts in energy sources. These shifts will result in environmental effects that today are not clearly foreseen. The EPA should undertake long-term research that will provide information on the environmental results of future energy developments.

For example, in the near future, coal use will increase in the U.S. and so too will CO_2 and SO_x emissions. Today we have acid rain. How extensive will the area affected be in the future? What effects are most important--decline in fish productivity? in agricultural crops? or perhaps in forest growth? What can be done to mitigate these effects? Are the effects reversible?

As for CO_2, the question of climatic changes is probably of greatest import. What will be the net effect on arable lands? on yields per acre? on location of lands?

We cite these questions not as specific ones requiring answers, but rather as examples of the scale and scope of questions requiring answers. Obviously, proper answers will be vital as a basis for decisions on land use, determination of carrying capacity, and indeed measures of the quality of life itself. We still have no clear understanding of the functioning of ecosystems used by man. Without such fundamental information, we will be unable to measure changes and predict the appropriate course of action for society.

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REPORT OF GROUP 2

HUMAN EXPOSURE

Prepared in Response to Questions from the

U.S. Environmental Protection Agency

Questions

Human Exposure

The recommendations for new research within this subject area do, for the most part, provide sufficient detail to be included in the initiative package. Please provide any additional information which the panel feels will make a more persuasive case for funding these proposals--information which better conveys what specific research products are desired, why these products are important, and what research activities must be undertaken.

1. Use and development of personal dosimetry for measurement of human exposure to the seven air quality criteria pollutants.

2. Measurements of population exposures to air carcinogens in the vicinity of stationary sources.

3. Improved source characterization for non-criteria pollutants. Back-up information is especially needed for this recommendation, particularly with respect to which pollutants should be examined and why.

4. Characterization and measurement of personal exposures in special environments.

5. Improvement of techniques for the multi-residue determination of pesticides, metabolites, and degradation products in human tissue and the environment.

6. Development of techniques and guidelines for measuring frequencies, modulations, and power levels of radiation for levels less than infra-red.

7. Dosimetry studies for exposure to non-ionizing radiation in different functional environments.

8. Development of a strategy for determining human exposure to toxic chemicals from existing chemical waste sites. (Human Exposure and Sources-Ambient Levels)

9. Improvement of analytical techniques for collection, identification, and quantification of pollutants in all media.

Recommendations 5 through 9 are in definite need of back-up material along the lines described in the introductory paragraph.

Most of the recommendations identified as high priority within the following subject areas are sufficiently developed to enable ORD to begin formulation of an initiative proposal. These recommendations are listed below along with pertinent comments which the panels may wish to consider in developing their response to this review. Any additional information which the panels feel clarifies what products would be produced, why they are important, how they will be used and what research is necessary to produce them would be greatly appreciated.

Teratogenic/Mutagenic/Reproductive Effects

1. Carry out epidemiologic studies to investigate the effects of specific environmental chemical exposures on the male and female reproductive system.

2. Extension of reproductive toxicity studies in females to address other end points.

3. Development of new methodologies to measure the occurrence of ovulation, fertilization, and spontaneous abortion.

4. Conduct of animal studies of reproductive toxicology modeling the human exposure condition. ORD's research currently addresses this recommendation, but because of the high priority placed on teratology and reproductive methods development by EPA's Office of Toxic Substances this area could be significantly expanded.

5. Development of _in vitro_ teratogenesis test systems using organ and whole embryo cultures.

6. Conduct of research to identify inherent species differences in responses to reproductive toxicants.

Recommendations 4, 5, and 6 are currently being addressed but on a small scale.

7. Conduct of research to determine the susceptibility of spermatogenesis to environmental insult.

This recommendation represents an excellent area for development of screening methodology.

Neurological Effects/Behavioral Toxicology

1. Undertake a critical review of currently available electrophysiological measures and behavioral methods. Electrophysiological, behavioral, and physiological work is covered in ORD's FY 80 work plan. Areas not covered, however, include biochemical and morphological research.

2. Validation of existing methods for assessing animal toxicity. This is an area already addressed by ongoing research. However, a new aspect of this recommendation would be for EPA to obtain and analyze data for longitudinal studies (e.g. perinatal exposures).

Carcinogenesis/Mutagenesis/Immunology

1. Development of better close extrapolation methods from high to low dose exposures and from animals to humans. Work is already underway to improve extrapolation from animals to man but nothing is being done in the area of extrapolation from high dose to low dose.

Cardiovascular and Other Chronic Disease

1. Definition of pollution levels which do not cause adverse effects in vulnerable subsets of the population. EPA is doing limited research in this area but expansion of our current effort is needed to identify susceptible populations.

2. Development of animal models for identifying the effects environmental contaminants have on cardiovascular and renal systems. This is also an area where limited research is being conducted but could benefit from an expanded effort.

3. Conduct of better quality epidemiologic studies. This recommendation is very important but extremely vague.

4. Conduct of clinical evaluations of persons with known exposure to contaminants.

5. Development of immediate field investigation capability for study of populations inadvertently exposed to hazardous agents.

Recommendations 4 and 5 deal with areas which are very important where EPA is missing many opportunities to conduct research. The panel should be very specific in its response to these recommendations.

COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University

and

The Environmental Protection Agency

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Preface

Many of the recommended investigations of possible effects of hazardous chemicals on man can be implemented, where possible, when industrially employed populations are exposed to definable chemical and/or physical agents in the course of their employment. The physiological characteristics of the industrial work force population at risk will differ from that of the general population, but levels of pollutant exposure will almost certainly be one or two orders of magnitude greater than those to which the general population is exposed, thus increasing the probability that untoward effects will be detected. The low exposure concentrations in the community require the use of more sophisticated techniques to discriminate similar health effects.

Occupational groups are covered under Toxic Substances Control Act (TOSCA) legislation. We recommend that the EPA, in conjunction with the Occupational Safety and Health Administration's (OSHA) record-keeping requirements, develop environmental monitoring and reporting of industrial health data, perhaps limited to industries larger than a certain size. Ideally, the availability of these data can provide new information on human dose-response relationships. We also recommend that health-related research on effects of air and water pollution or pesticides be coordinated with data obtained from occupational exposures, as a major supplement to epidemiologic studies of population groups not occupationally exposed.

Human Exposure

Question 1

It is important to determine the breathing zone integrated 24-hour exposures of individuals to the seven Air Quality Criteria Pollutants (AQCP) and to contrast the exposures of a variety of persons at different locations, to fixed station sampler results, as currently reported. Instrumentation for dosimetry can be mounted on subjects (personal samplers) or a time-weighted-averaging technique based on multiple fixed-site location samplers could be used, with estimators of person exposure time at each location. Quality control procedures should be an integral part of the design of these investigations. The questions to be answered are highly pertinent to (1) the reliability and validity of currently cited epidemiological studies which have utilized fixed location samplers as measures of pollutant dosages to the population and (2) the appropriateness of current primary standards for the seven AQCP.

Question 2

Current and past air-borne carcinogen measurements are at National Air Sampling Network (NASN) stations. We do not know the gradient of air-borne concentrations as a function of distance from sources such as petrochemical facilities and steel plants. The dosages received by the population, in accordance with (1) above, are the ultimate measures desired. These data are needed to lend support to the EPA Cancer Assessment Group's efforts.

Question 3

The Committee discussed the recommendation for both air and water media. For air, we are aware of the EPA Particulate Emissions Inventory for individual sources which have been tested on site; we recommend expansion of this machine-based data bank and a concentrated effort to obtain particle size distribution data for source emissions. Emphasis should also be placed on obtaining data for vanadium, nickel, cadmium, and organic emissions, particularly those adsorbed on particulate emissions.

For water emissions, a data bank similar to that for air emissions is needed to store characteristic emissions data from different standard industrial classifications (SIC's). Emphasis should be on systemic poisons and organic compounds, as in the case of air emissions.

Question 4

Sporadic investigations suggest that exposures to air-borne pollutants in hospitals, homes, bars, restaurants and other special environments can present formidable challenges to the respiratory system, particularly for those afflicted with pulmonary conditions. The Committee urges that these air environments and the dosages to occupants of these environments be more completely defined.

Question 5

In the EPA, methodology for monitoring pesticides in air, water, soil, house dust, and human tissue is largely based on the Food and Drug Administration (FDA) multi-residue procedure. For this reason the argument can be made that, in general, pesticide monitoring data are comparable across federal programs. In recent years, reorganization and funding decisions, coupled with a dramatic change in the nature of chemicals used to control pests, have seriously impacted the status of the multi-residue methodology.

The problem is intensified because many of the "new" pesticides are no longer directly amenable to gas chromatographic analysis. However, derivation procedures have proliferated which allow the continued use of gas chromatography interfaced with a variety of detectors to be the principal approach to the problem. The new methodology requires a better skill mix than usually exists in monitoring laboratories outside the federal government and is no longer multi-residue in nature.

The research needs broadly outlined below reflect the specific mission of the EPA; however, the research activities should be closely coordinated with the FDA, Fish and Wildlife Service, U.S. Geological Survey, and other federal laboratories involved in pesticide method development activities. Additionally, the Office of Pesticides should continue to receive support from the Office of Research and Development-Research Triangle Park, particularly in the area of quality control.

(a) Develop a multi-residue methodology applicable to human tissue and environmental media for pesticides currently of importance in agricultural practice.

(b) Develop and evaluate media for trapping pesticides from air and water.

(c) Develop a methodology for determining the extent of human exposure to pesticides on the Rebuttable Presumption Against Reregistration (RPAR) list.

(d) Develop an analytical scheme (cleanup procedures, column technology, etc.) for confirming the identity of pesticides and metabolites by gas chromatography-mass spectrometry (GC-MS). The investigation should emphasize GC-column technology and methods for cleaning up samples prior to GC-MS analysis.

Question 6

Simple basic instrumentation for making these environmental measurements is needed which will include power density and electric field measurements. The many existing methods and instrumentation should be studied to determine if they can provide the sensitivity and complete information required to characterize exposures. Instrumentation should be developed for those frequency ranges not covered by existing instruments. Design features of existing instruments should be considered for use in frequency ranges that cannot be measured at this time.

Question 7

Measurements of dosage should include: (1) frequency characteristics, (2) power level, (3) total duration and time exposure pattern, (4) peak to root-mean-square ratio of signal, and (5) characteristic pulse shapes. Measurements should involve exposures to citizen band radios, amateur radios, broadcast station radiation, and power lines. Consideration should be given to the physical condition of those persons exposed, and to the effects of radiation on personal appliances such as pace makers and prostheses.

Question 8

A methodology is required for evaluating the types and magnitudes of emissions from these sites and the magnitude of human exposures resulting therefrom. The purpose of the recommended investigations is to place the potential human exposure problem from waste-site chemicals on a more quantitative basis than currently exists.

Question 9

Because pollutant measurement techniques are basic to the mission of the EPA, we recommend continuous research efforts to improve analytical methodologies. The analytical results will almost certainly be required to meet higher standards of performance in the immediate and distant future.

Teratogenic/Mutagenic/Reproductive Effects

There is a new awareness of the extent to which exposure to environmental insults can endanger the reproductive system. Current evidence implicates waste disposal (Love Canal), exposure to pesticides, and possibly exposure to some defoliants. Moreover, recent advances in reproductive research also indicate that a surprisingly low level of exposure to harmful substances may have adverse effects, and that these can be detected. Fortunately, some of these effects are mild in manifestation, but they offer the hope that their study will provide a non-invasive and relatively inexpensive system of monitoring the environment. Our recommendations, therefore, give priority to research which explores the use of these new methods.

Specifically, the new initiatives recommended deal with three new types of end points:

(1) spontaneous abortions;

(2) studies of sperm (sperm DNA, head shape assay); and

(3) prenatal laboratory data (alpha feto-protein, in serum; chromosome studies; and alpha feto-protein in amniotic fluid).

Because these areas of research are still little known, each will be described more fully below.

(4) We also recommend the further development of animal studies of reproductive toxicology, modeling the human exposure condition.

This model should address parameters intrinsic to the reproductive toxicant and to species differences in reproductive systems. The shape of the dose-response curve for various reproductive toxicants needs to be determined for extrapolation from high-dose animal studies to low-dose environmental exposures. Pharmacokinetic parameters such as absorption, metabolism, and excretion should be addressed as they relate to the dose-response relationship.

Inherent species differences in reproductive systems have to be defined and models developed that incorporate these differences into the performance of risk assessment. Rodent reproductive systems differ greatly from human, for example, in that (1) they possess placentas that differ anatomically and functionally; (2) they possess an estrus cycle instead of menstrual; (3) their fetuses, in contrast to humans', lack liver mixed function metabolism including Aryl Hydrocarbon Hydroxylase; (4) they have differences in the blood-testis barrier; and (5) they are more susceptible, compared to humans, to chemically induced abortions. These differences between rodent and human reproductive systems need to be better defined and quantified in order that they can be incorporated in the risk assessment process of the EPA.

Recommended New Initiatives

1. SPONTANEOUS ABORTIONS

It is now known that the great majority of defects occurring in a human conceptus, whether the defect originates in sperm or egg, will result in a spontaneous abortion, and a similar fate also results from many maternal exposures between conception and birth. Studying this system, therefore, provides a check on the great majority of adverse effects of human reproduction, probably excluding only those that interfere completely with fertilization, or those that have delayed effects.

Information that can provide useful data for the EPA is considered at three levels:

I. Crude frequency data, based on large hospital series that can be coordinated with ongoing live birth data.

II. More detailed frequency data, which include specific background information on the population, and take account of spontaneous abortions occurring within and without hospitals.

III. Intensive studies of spontaneous abortions that include questionnaires relative to demographic details, clinical data, and possible exposures; and morphologic and karyotypic studies of the aborted specimen.

I. Crude Frequency Data

It is proposed that existing data bases be examined for their usefulness in supplying this information. In particular, the Center for Disease Control

(CDC) currently publishes information on birth defects, live births and stillbirths, based partly on CPHA records, and partly on three separate population series. If some, or all, of these sources could be adapted so as to include information on spontaneous abortion (preferably including age of mother and duration of gestation) then this would become a valuable resource, covering a large part of the country.

It would have the disadvantage of being limited to hospital users (which may not, in itself, be a serious limitation for spontaneous abortion studies). It is also not representative of all sections of the population.

It would have the advantages of using an ongoing system professionally handled and analyzed. Fluctuations of abortions, by time and by place, could be more meaningfully interpreted, given the ongoing information on live births and malformations.

If it, therefore, seems useful for the EPA to explore the possibility of a joint initiative with CDC in this regard, the EPA would definitely require some new elements to be introduced into the system:

(1) the registration of spontaneous abortion;

(2) the last menstrual period of the woman; and

(3) the age of the mother.

There are two other desiderata of the system:

(4) the possibility of generating more intensive studies, if and when an apparent "epidemic" is detected, without delay; and

(5) the ability to analyze the data in such a way that cohorts of conception could be studied.

II. More Detailed Frequency Data

These types of data should be generated for two purposes:

(1) to validate the findings related to frequency, in the crude frequency data, especially to allay concerns about selective use of hospital services; and

(2) to establish baseline data for spontaneous abortions for men and women in everyday exposure categories (e.g., smoking, alcohol, oral contraceptive usage). Preliminary information is available for these, but this information should be extended to firm up the use of abortions in monitoring for environmental exposures. Information of this type enables control of confounding to be achieved.

If the primary purpose is (1) above, it might be recommended that one of the areas currently included in the CDC system be utilized (e.g., Atlanta, Georgia; Nebraska; Florida--all of which are population based). Another possibility is a prospective series (such as the Kaiser Permanente population, studied at Walnut Creek). A third is to generate a new source, where hospital utilization is known to be low. One or more of these approaches could be followed.

III. Intensive Studies

Spontaneous abortion specimens can be studied in some detail, yielding information about the likely cause, the timing of the hazardous event, and the parental origin. A start has been made in this field, so that baseline information exists for determining, for instance, the probability that, if there has been an excess of abortions, whether the insult was pre- or post-conceptional.

At present, pooling international series, an expected estimate could be made of the changes of an excess of one type or other for abortions occurring in women of given age groups. However, if the system is to be used in the field, it would be preferable to generate studies that included suspected exposed and suspected unexposed groups in every investigation.

A standard protocol would need to be developed, including estimates of appropriate sample sizes for the particular comparison.

It is recommended that appropriate intensive studies be developed that will explore the likely effects of low-level exposures, whether of the man, the pre-pregnant woman, or the pregnant woman. Such studies would best be carried out where the exposure can be well characterized and where a reproductive hazard has been suspected, or is coherent with biologic influence.

In those cases arising from levels I and II above, where there is reason to suspect that an "epidemic" level of spontaneous abortion or congenital malformation exists, similarly intensive studies of abortions should be carried out in that area.

2. STUDIES OF SPERM

Although high exposures to substances likely to endanger sperm have usually been connected to industrial settings, still we have little to guide us in monitoring studies in the work place. Moreover, male infertility has been implicated in men exposed to pesticides, so that investigations into effects on sperm have come into the purview of the EPA. The effects of exposures on sperm are often furtunately short-lived (affecting only the spermatocytes). Even during that short period, however, they may lead to infertility, and possibily to conception of defective zygotes.

Therefore, studies of the sperm by new techniques are recommended, which seem to relate both to low-level exposures on the one hand and to functional deficiencies on the other.

Research is recommended to determine the susceptibility of spermatogenesis to environmental insults. Mutagens, in order to produce an inheritable mutation resulting in an increase of the genetic burden in humans, must interact with the genetic material (DNA) of sperm or ovum. Methods need to be developed to measure chemically induced damage to sperm DNA. These assays will be used to determine that an environmental toxicant has crossed the blood-testis barrier and altered the genetic material. The relationship of this DNA damage to chemically induced inheritable mutation is a high priority task in order for these proposed assays to be used as molecular markers, both qualitatively and quantitatively, for chemically produced increase in the genetic burden. Species variations in DNA repair rates also need to be determined since they will alter the relationships between initial DNA damage and resulting increase in genetic burden.

A correlation should be attempted between chemically induced DNA damage and abnormally shaped sperm heads. Both assays attempt to measure the appearance of a chemical mutagen in the testis. Since the mechanism of chemically induced, abnormally shaped sperm is unknown, a correlation with DNA damage would argue for a mutational process in their induction. It is of very high priority that the EPA apply its resources to the validation of sperm DNA damage and abnormally shaped head assays, so that they can be used in the detection of chemicals capable of increasing the genetic burden and causing cancer.

3. STUDIES BASED ON PRENATAL LABORATORY DATA

Increasingly, women are being screened, during the prenatal period, by serum tests and by amniocentesis. The clinical reasons for carrying out these studies are to detect the risk of neural tube defects on the one hand, and chromosomal anomalies on the other. It is suggested that, as a fringe benefit of these investigations, they could be utilized to detect changes between sub-populations, and over time.

In order to carry out this type of study, more detailed epidemiological information would be required than is currently collected as a routine by many laboratories and hospitals. It would seem useful to pilot a scheme for a protocol record to be used more widely, to explore whether these data sources could serve the purposes of environmental monitoring.

Neurological Effects and Behavioral Toxicology

Question 1

It is recommended that appropriate specialists be recruited to undertake a thorough evaluation of the utility of non-invasive behavioral and neurophysiological methods not currently in use in toxicological investigations (but of proven value in various other disciplines) to provide reliable, quantitative data for assessing alteration of the functioning of the human central and peripheral nervous systems due to exposure to presumptive toxic agents. Such an evaluation would include a critical review of the literature (English and non-English), site visits to appropriate laboratories to obtain first-hand (perhaps even hands-on) knowledge of the applicability of the techniques and validation of the utility (accuracy and sensitivity) of the techniques employing, ideally, cases of actual human exposure.

Validation of the utility of new (in the sense of not having been used previously or extensively in toxicological studies) non-invasive techniques would necessarily require correlation and integration of electrophysiological, behavioral, physiological, biochemical, and morphological data, both in exposed humans and in appropriate animal models.

Question 2

Validation of existing methods for assessing animal toxicity requires that information addressing the effects of toxic agents on behavior, neurophysiology, morphology, and neurochemistry be correlated both in acute dose-response relationships and long-term, low-level toxicity. It also requires a precise understanding of the mode of action of toxic substances at different stages of development. Comparisons of the effects of human exposure to toxicants at various stages of development are recommended.

This group has recommended new initiatives and urges their implementation. Specifically, the urgency of a thorough evaluation of new non-invasive behavioral and electrophysiological methodologies cannot be over-emphasized. Likewise, an in-depth understanding of the effects and mode of action of toxicants at various stages of development is of vital importance to public health and regulatory activities.

Carcinogenesis/Mutagenesis/Immunology

Question 1

Historically, most carcinogens have first been detected as a consequence of human exposure and only secondarily confirmed in animal trials. Contemporary attempts to reverse this sequence continue to be frustrated by intrinsic idiosyncrasies of animal systems related to carcinogen activation, pharmacokinetics, tissue susceptibility, etc. There are additional problems related to establishment of dose-response curves. The simplest quantitative relationship is assumed to be linear and tumor yield should be proportional to dose. In actual practice, this simple relationship does not prevail across a broad spectrum of pure compounds or mixtures. For example, the tested agents might induce pharmacologic effects at high dosage which are not detectable at low dosage. Therefore, under this contingency, the dose-response relation is not linear. Nonlinear dose-response curves tend to confuse interpretation and extrapolation of high-dose studies. For this reason, single-dose studies do not differentiate quantitative-qualitative relationships; at least three doses are required.

Extrapolation of dose-response relations from animals to man is subject to additional difficulty. There may be fundamental differences in initiator-promotor interactions in laboratory animals and man. For many carcinogens studied in rodents, latency of tumor induction is often inversely proportional to dose. Thus, low dose studies may lose sensitivity as the limit of the host's life-span is approached. In contrast, human studies have not found a shortening of latent period with increasing dose (for example, Tokunaga, et al., 1979). Therefore, the latent period for human tumor induction is likely to be measured in terms of decades and will probably not be shortened even by the higher doses. This observation argues for long-term follow-up studies on carefully documented human exposures. Sequelae with long latency could best be revealed directly in long-term studies of the human population. Since it is not feasible to conduct human studies in all instances, animal studies will be necessary. Extrapolation of findings of animal studies to humans should be done with caution, especially with regard to dose-response relationships.

Prospective studies on the long-term consequences of carcinogenic exposures have been most often applied to ionizing radiation studies (Atomic Bomb Casualty Commission, rheumatoid spondylitis irradiation exposures, thyroid cancer following thymus irradiation, etc.) and the methodological lessons learned and the mistakes detected could form the foundations for analogous studies on other carcinogens.

Such prospective studies could include the following features:

(1) accurate determination of exposure levels;

(2) identification of exposed individuals;

(3) accurate determinations of total dose and dose rate of exposures for each individual; and

(4) long-term follow-up (20-30 years to lifetime) of exposed individuals and appropriate matched, unexposed controls. Such follow-up would be continuous despite out-migration and should include routine history, physicals, laboratory studies, and autopsy data, where feasible. Death certificate data are an unacceptable alternative to these specified end points.

The panel recognizes that the proposed long-term follow-up studies are likely to be expensive and require a sustained input not previously employed by the EPA. However, long-term observations of exposed human populations are likely to provide direct answers to risk assessment. The benefits to be attained in terms of dose-response data clearly warrant the expenditures of time and money.

In summary, the panel recommends:

(1) animal dose-response studies should include at least three doses and attempt to minimize distortion of the dose-response curve; and

(2) since human tumors are associated with a latent period which may extend for decades, long-term follow-up studies are required to detect increased frequency of human tumors after exposure to environmental agents.

Cardiovascular and Chronic Disease

Five items from this panel were mentioned by the Office of Research and Development (ORD) as needing further evaluation; some of these were related to recommendations by other panels, especially the panel on Carcinogenesis and Immunologic Effects.

Question 1

The panel report attempted to single out certain groups potentially at special risk, such as those with allergies. We interpret the EPA concern in this area to indicate that the ORD review group considers that this concept is important and requires extension. The panel on teratogenic and reproductive effects has addressed the matter of pregnant women as a particularly sensitive group.

Other sensitive groups will depend, of course, on the nature of the effect produced by the agent of interest, and generalization applicable to all agents is not possible. Nevertheless, some general concepts may be helpful in defining unusual risk groups.

Older age groups will be at special risk for agents which produce degenerative effects on the lungs, kidneys, or vascular system. Those individuals with atherosclerosis or arteriosclerosis will be a high-risk group for agents whose effects interfere with the chain of oxygen delivery, from the lungs to blood transport to the integrity of the vasculature. Young people and children may be at particular risk for those agents that produce cancer or other diseases with long latent periods and with a probability of occurrence that is proportional to years at risk. For agents that produce relatively acute effects, children may be at special risk because of their high ventilatory and metabolic rate in relation to organ size, which leads to a higher acute dose to the tissues than for adults. Individuals with a pre-existing disease of a vital organ, such as the liver or kidneys, are usually at special risk from agents that have toxic effects on those organs. In every one of the instances cited above, the groups at special risk constitute a significantly large subset of the entire population.

Question 2

The panel on cardiovascular and other chronic disease did not lay particular stress on this approach, and indeed concluded that the principal value of animal modeling in investigating effects of environmental agents is in defining the mechanisms of actions of these agents. The translatability of animal data to humans is fairly good for effects on the kidneys or liver, for example, in contrast to effects on the nervous system or lungs. The current review group did not consider greater emphasis by the EPA on animal modeling to be especially worthwhile.

Question 3

The use of epidemiologic methods to study effects of chronic exposure to environmental agents is still in its infancy, and the field has been plagued by inadequacies of design in the studies that have been done. Some general methodologic principles are worth stressing. This problem has recently been extensively reviewed by the Interagency Liaison Regulatory Group.

Retrospective studies: These studies have the great merit that chronic diseases with long latent periods from onset of exposure to a detectable abnormality are accessible to investigation now, in contrast to true prospective studies, which may yield results only after years or decades. The principal problem with retrospective studies is that exposure doses are often poorly known, and the value of such studies to the EPA's mission is largely dependent on how well the exposure to the agent under study can be defined in the study group compared to the controls. A related problem is the extent to which confounding agents which are widespread in the population influence the disease end point under study. Retrospective definition of the prevalence of a major confounding variable, such as cigarette smoking, for example, may be sufficiently difficult as to render the study invalid. Case-control studies gain greatly in value if even two or three levels of exposure to the environmental factor can be incorporated into the design, rather than relying simply on a yes or no exposure categorization.

Non-concurrent prospective studies not only require good historical exposure data but also depend on identification of the study population which is not biased *a priori* in terms of follow-up capability. In short, follow-up potential of the population selected should be good, with prospects of loss to follow-up of less than 5 percent. This is especially important for chronic diseases, such as cancer or pulmonary diseases, where loss to follow-up may be strongly influenced by the disease under investigation. In the case of retrospective studies of occupational groups, adequate follow-up of retired workers is mandatory, and almost as important is the follow-up of workers who have left employment in the industry before retirement. A frequently ignored problem in occupational studies is previous experience with potential confounding exposure to agents in one or more jobs other than in the work group under study.

Cross-sectional studies of disease prevalence in exposed populations have their chief, immediate value in detecting acute effects of the agent, such as may occur from widespread accidental exposures. Although it is possible to assemble at the time of the study some historical data to investigate chronic effects, if such are possible, long-term effects of exposure are best evaluated by establishing the study design so that a prospective follow-up of the group can be facilitated.

Prospective studies are of great potential in establishing dose-response relationships, even at low doses, but the great expense and commitment of resources involved means that special care is required in designing them. Moreover, for studies of chronic diseases with long latent periods, the follow-up time required may be several decades. Thus, immediate results should not be expected. Indeed, a commitment to long follow-up is an important part of the study design, if the definition of long-term effects is desired. While study of effects of very low doses of an agent is especially useful to the EPA, there is a potential limit arising from statistical considerations on how low the exposure can be to produce effects that are detectable in comparison to those observed in the control population. If there is a background of exposure of the general population to the agent (for example, ozone) chronic exposures in the study group should, at a minimum, be about three times higher than the background to offer a chance to detect an effect. This rule of thumb obviously depends on the sensitivity of the disease process to induction by the agent. If prospective effects of an acute exposure to the agent are to be investigated, the possible influence of background exposure must be carefully evaluated in the study design.

The statistical power of the study should be evaluated in advance, and the minimum population size to define a positive effect determined as a function of the magnitude of the effect. The size of the available population may be too small to detect small increments in disease risk. This consideration applies to retrospective studies as well, but it is crucial for prospective studies. Also common to all epidemiologic investigations is the choice of an appropriate control population. This is often a problem when the effect under study is morbidity determined by functional testing, because good data on the functional test in a "normal" population must be available in advance. Even for relatively clear-cut end points such as cancer, the incidence in unexposed populations is sufficiently variable as to require care in selection of the control group.

Unless most or all of the above criteria for epidemiologic studies can be met, it is questionable whether the study should proceed, especially if the intent is to provide human dose-response data for regulatory purposes.

Question 4

Stress on this type of investigation arises from the fact that experimental exposure to human subjects in the laboratory is now virtually impossible. Therefore, opportunities for investigating exposures must be exploited wherever they occur. Under this heading would be particular groups occupationally exposed, with long-term follow-up the main goal. Such an evaluation is not easy to establish as an ongoing process. The biggest problems to be overcome are either to provide highly skilled and continuing professional evaluation at the location where exposures are occurring or to have exposed patients regularly referred for evaluation to an out-patient clinic or special hospital ward. The latter is the most practical approach, but there are formidable obstacles to its implementation. This recommendation largely depends on overcoming institutional limitations now impeding these kinds of evaluations. Sophisticated clinical methods are available, but measurement of previous exposure can be a problem.

Question 5

The panels on chronic disease and on carcinogenesis both stressed this approach. Definition of the skills required in a team that could respond within hours to a sudden exposure situation was given in the chronic disease report. It is vital that all elements of this team be represented in planning, and be available for the immediate response.

The present review group has concluded that it is extremely unlikely that the EPA will develop this type of capability in house, nor is it necessarily appropriate for any federal agency to do so. We recommend that about three or four "response centers" located throughout the country be established by the EPA at academic medical facilities with the requisite measurement, epidemiologic, laboratory, and clinical capabilities. These groups would be on call for emergencies. In order to maintain a highly competent staff ready on a continuous basis, support for these centers would have to be continuous and substantial, especially as back-up personnel would have to be available in some depth in order to assure that a full team could respond quickly at short notice.

We agree that the EPA is missing important opportunities in this area. A precedent for developing this capability has already been established by the Center for Disease Control.

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REPORT OF GROUP 3

MEASUREMENT AND ANALYSIS; SOURCE CHARACTERIZATION AND CONTROL

Prepared in Response to Questions from the

U.S. Environmental Protection Agency

Questions

The Office of Research and Development's analysis indicates that the vast majority of research recommendations associated with the following subject areas are already being addressed by ongoing EPA research programs. Most of these programs could, however, benefit significantly from an influx of additional resources. This is especially true for the recommendations dealing with hazardous waste. In order to provide an appropriate justification for additional resources, it is critical that the panels precisely identify what new products they feel should be developed above that which would be expected from the current programs, why these products are needed, and what new research activities would have to be undertaken to produce them. Those recommendations identified as high priority in light of current EPA program philosophies, orientations, and needs are listed below.

Separation and Treatment Technology

1. Development of controls for diffuse air pollution and non-point source water pollution.
2. Development and demonstration of improved hazardous waste control technologies, including better methods of containment and/or treatment of hazardous waste spills on land and water and mobile and on-site methods of hazardous waste removal, detoxification, and containment.
3. Assessment of toxic emissions and control options for sludge and/or refuse disposal by thermal conversion processes.
4. Characterization and evaluation of the fate and effect of the organic fraction of sludges.

Process Change/Product Substitution

1. For process change and product substitution, development of (a) analytical methods for the detection of traces of hazardous substances; (b) rapid and economical test methods for determining a substance's toxicity; and (c) a meaningful relationship between chemical structure and toxicity.

Ultimate Disposal

1. Development of new technologies to implement all approaches to ultimate disposal. It would be helpful for the panel to identify a set of

criteria for identifying when containment is preferable or acceptable, i.e., does the choice of containment depend on economics, type of waste, or desirability of future reuse?

2. Development of an improved understanding of the effects of economic and regulatory incentives/disincentives on approaches to ultimate disposal.

3. Development of improved methodologies to quantify the hazards presented by various potentially polluting materials.

4. Establishment of criteria to correlate hazard levels and optimal disposal methods.

COOPERATIVE AGREEMENT FOR THE EVALUATION OF CURRENT ENVIRONMENTAL RESEARCH AND ESTABLISHMENT OF PRIORITIES

The Pennsylvania State University

and

The Environmental Protection Agency

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Separation and Treatment Technology

Question 1

The EPA should characterize and evaluate best management practices for control of priority pollutants.

In regard to this, many of the industrial and mining non-point air pollution sources need the application of directives, engineering, and enforcement rather than research by the EPA, inasmuch as many of the solutions to the problems are readily conceivable. Some of the problems can be solved by strict enforcement of Occupational Safety and Health Administration (OSHA) recommendations. Examples of some of the industries contributing significantly to non-point air pollution are lime plants, iron and steel plants, coal mines, chemical plants, and petroleum processors, including the transportation aspects.

A particular source of diffuse emissions that needs increased research attention by the EPA is the particulate and NO_x effluent from diesel engines in automobiles, trucks, busses, and trains. Higher NO_x emissions are inevitable in the lean burn range exhibited by diesel engines in comparison to gasoline engines.

A source of diffuse air pollution of concern is associated with roadways, particularly asbestos from brake pads. Other aspects include the fate of particulates from tire and roadway wear and the effects of de-icing salt and cinders on air, water, and land pollution.

Some of the non-point water pollution problems of concern are associated with the mining industries. In particular, coal mining has destroyed the quality of many streams in the Appalachian region. The EPA should become more involved in the pursuance of cleanup of streams, especially where the principal pollutant source is water seeping from abandoned mining operations. One example of the possible consequences of inaction is the ill-fated attempt by the Army Corps of Engineers to build a massive "acid mine water" storage reservoir in the west branch of the Susquehanna River for purposes of flood control. Possibly the most reasonable economical treatment of such streams will involve the use of limestone as the neutralizing agent.

In the area of non-point water pollution sources, agriculture should receive the same sort of attention by the EPA that is extended to the chemical, petroleum, and mining industries. Overfertilization and poor application management cause dispersal of nitrates, phosphates, insecticides, and herbicides, contributing to air and water pollution problems. The extent to which agriculture contributes to the acid rain problem should be more thoroughly researched. Better control of erosion is needed to abate the negative effects of sediment on the quality of streams and lakes. The sediments carry along and disperse the agricultural chemicals applied to the soil.

More concern should be applied to the pollutants that didn't make the EPA priority list of hazardous pollutants--that is, those that affect drinking water quality. These include sulfate, chloride, and sodium concentrations in effluents that can significantly affect stream quality.

Question 2

The EPA should develop criteria for ground water quality or land use practices which will permit the determination of which control technologies are adequate for handling hazardous waste spills.

Better enforcement and improved methods are needed to clean up oil spills on water and to absorb spilled chemicals from surfaces and water. For resort beach areas, there is a need for a mobile sand cleaning machine capable of cleaning up oil spills.

There is a need for upstream monitors for municipal water and sewage treatment plants to provide pre-warning of accidental spills of chemicals from industrial sources. This requires the development of remote sensing devices for hazardous wastes. It is probable that diversion of the stream may be necessary if holding of the contaminated water isn't feasible.

The use of remote sensing technology should be investigated to determine its role for detecting and monitoring hazardous waste dispersal into waters and land and/or the indirect effects of the hazardous wastes on the ecosystem. Aircraft and satellite-mounted sensors could be used to acquire data in the reflective, infrared, and thermal regions of the electromagnetic spectrum and the resulting data evaluated for information content.

Question 3

In general, it is preferable to store sludges and refuses in land disposal sites or to compact and dry them in basins, rather than use thermal conversion processes (incineration) which require considerable energy and could disperse hazardous pollutants into the atmosphere. This is especially true for sludges containing inorganic hazardous materials that are not converted to an innocuous form by oxidation or thermal decomposition.

Incineration should be limited to situations where there is no practical alternative. For example, if the sludge contains very toxic organic compounds, the use of expensive high temperature incineration followed by scrubbing can be justified in order to destroy and contain the toxins. The EPA should become involved in research to design incinerators that enable complete combustion of the hazardous materials and to ensure that toxic by-products are not produced.

The EPA has evaluated metal emissions from sludge incinerators using Venturi and impingement scrubbers. Co-incineration of sludge and refuse, pyrolysis and alternate air quality controls, such as electrostatic precipitators, require evaluation.

Question 4

Sludges have been extensively characterized for heavy metal content, but not priority pollutant organic content. The EPA needs to identify the range of concentrations of priority organic pollutants in sludge, evaluate the removal and/or transformations associated with alternative stabilization processes, and their effect on ground water quality and agricultural processes.

A particular example of need for knowledge on the fate and effect of the organic fraction of sludges on the ecological system concerns insecticides. Spring Creek in Pennsylvania has been closed to stocking of trout because of contamination of fish and bottom sediment by Kepone and Mirex, manufactured upstream a decade ago. Evidence of contamination of well water in the vicinity has recently been found. There is a need to develop models to predict the transport and degradation of toxic chemicals once they get into in-stream beds and subterranean strata in order to provide some guidance as to what actions should be taken.

Process Change/Product Substitution

Question 1(a)

The need for faster, less expensive, more sensitive and simpler analyses will probably always be insatiable. The ability to analyze for pollutants of all forms is a necessary precursor for the formulation of standards and vital for enforcement. Qualitative methods for identification of pollutants are needed, as well as quantitative methods.

General Recommendations

Analytical techniques must encompass all phases--liquids, solids, and gases. In each instance, the development of adequate sampling techniques must accompany the analysis.

The areas of application for which new and improved methods and equipment are needed are:

1. Field Techniques. Simple, reliable, relatively inexpensive methods which do not require high skills to use are needed for detection of pollution and sources, as well as for the enforcement of regulations. Applications of field techniques can range from effluents from steel mills to the detection of

noxious contaminants on consumer items such as poultry, meats, and so forth.

2. On-Stream Analyzers. Continuous or high frequency intermittent analyzers are needed for monitoring or controlling flowing or regular sources of pollution, such as in-plant and effluent streams. The detection of duration from acceptable standards as they occur can lead to immediate correction. Slower laboratory methods can only reveal pollution which has already happened.

The characteristics needed in on-stream analyzers are reliability, accuracy, reasonable cost, and automation with minimum maintenance. The best examples of such equipment are gas chromatographs for hydrocarbon and some organic streams and, possibly, radioactive detection apparatus. Further attention should be given to:

(a) aqueous systems with dissolved electrolytes or organic compounds;

(b) solid streams and wastes covering organic compounds and inorganics, both metallic and non-metallic; and

(c) non-volatile liquid streams which cannot be handled by present chromatographic or instrumental methods.

We note that the developing gas chromatograph-mass spectrograph (GC/MS) is receiving much publicity. We suggest caution in relying on this system as the primary or exclusive method of analysis. This method is too expensive for control applications.

Specific Recommendation

The EPA should sponsor an inventory, or handbook, of sampling and analytical methods for the compounds and streams which it considers important. In such a rapidly moving field as this, maintenance of a handbook must be a continuing effort.

Question 1(b)

Without citing examples, it is apparent that some substitute products and some by-products (or intermediates) of alternate processes will require testing for toxicity. *If acceptance of the changes and substitutions is not* to be delayed, some attention must be given to accelerating tests for toxicity.

It is suggested that one possible line of research is the intensification of the study of differences in metabolic and physiological processes between the several species of laboratory animals. The evidence that some species may convert substances not of themselves harmful into toxic or carcinogenic compounds indicates one reason why different species often respond differently to a single compound. Differences in human metabolism, as between diabetics and others, might also be explored. Although this is, surely, a difficult area of research, improvement in our understanding of biochemical behavior can yield results. The newly introduced home pregnancy test kits which supplement the use of laboratory animal tests are an example of the value of such understanding.

There is an important interaction between this research and the following proposal for development of a correlation between structure and toxicity. The two lines, if pursued, must not be isolated from each other.

Question 1(c)

It is suggested that, as difficult or nearly impossible as the task may seem, a start be made now to relate molecular structures of organic compounds to toxicity or physiological behavior of those compounds. This topic is, of course, one which occupies many chemists, but progress in the specific area can be focused and stimulated by the action of the EPA.

The thousands of different organic compounds may be thought of as molecules constructed from a relatively small number of building blocks and linkages. The physical, chemical, and physiological properties of these compounds are determined by the presence or absence of such constituent groups and the form of linkages. It is well known that slight variations in the molecular structures of organic compounds result in startling differences in physiological properties. For example, tolvene has a negligible effect relative to benzene in causing blood dyscrasias and the difference is a single methyl group; similar small differences between members of the barbiturate family cause startling changes in toxicity or effectiveness; and stereo-isomers may have opposing physiological effects. At present we are unable, in any systematic way, to correlate the molecular structure with toxicity in a consistent and meaningful fashion.

The goals of this effort would range from the short-term ability to assign priorities in choosing compounds for testing to the ultimate one of reducing or eliminating testing for toxicity. The last is not apt to be realized, but it remains a worthy aim.

This research must be accompanied by an understanding of the forms and mechanisms of toxicity. One possible classification follows:

(1) Time
  a. Immediately toxic
  b. Slow--as cumulative poisoning, or carcinogenic, etc.
  c. Synergistic--as alcohol and barbiturate; alcohol and carbon tetrachloride

(2) Absorption of Toxicity
  a. Breathing
  b. Ingestion
  c. Absorption through skin

(3) Mechanisms of Toxicity

(4) Toxicity to Whom
  a. Humans
  b. Domestic animals
  c. Wildlife (animals, birds, fish--for example, DDT)
  d. Flora

Ultimate Disposal

The EPA's research efforts should be directed to the following aspects of "ultimate disposal," and in this order:

(1) recycling and secondary use approaches;

(2) destruction, detoxification, and redispersal approaches; and

(3) containment and long-term storage approaches.

The third approach is the least desirable and every effort should be made to develop techniques that encourage the use of the first two approaches.

The materials we are presenting do not apply to radioactive wastes. We would recommend that the EPA become more actively involved with the Nuclear Regulatory Commission in developing better-designed systems.

The following is a coordinated response to the questions raised by the EPA regarding the recommendations made by the Ultimate Disposal panel. Four questions were asked and the responses are given in reverse order.

Questions 3 and 4

The approach would be to establish criteria and/or classification systems for wastes according to their degree of hazardousness or toxocity. Wastes would then be tested and categorized into different hazard levels. Disposal methods would then be geared to the level of hazard.

The establishment of the criteria for hazard levels is in itself a research project of considerable extent. In the establishment of these criteria, the composition, physical state, biodegradability, leachability, and solubility of the waste should be considered. In addition, the specificity of the hazard, the manner in which the wastes break down, the relative length of time that the hazard persists, the hazardous effects of the decomposition products, and the precautions that must be taken in the handling of the wastes must also be considered.

Once the materials have been classified into categories, research projects should be developed to match hazards with the characteristics of the disposal techniques and the site characteristics. This would include the development of a technical handbook of disposal techniques. When land is used for disposal, site characteristics should be considered such as geology, soils, climate, topography, vegetation, and ground water. The accessability of the disposal site, as well as its proximity to population centers, would also be important factors.

Additional research is also needed to determine rate of plant uptake and sites of accumulation of heavy metals for different plant species. This information should also be included in the handbook of disposal techniques.

Research should also be undertaken to determine the decomposition rates of various hazardous materials under various types of storage or disposal methods.

Question 2

In response to question #2, costs should be established for each type of disposal approach. These costs should include the usability or by-product value of the waste.

Research should also be conducted to determine the factors that affect incentives and disincentives, such as ownership of disposal sites. This should be done by an interdisciplinary team including lawyers, economists, and sociologists. This team should investigate the legal aspects of incentives/disincentives and develop model legislation. A guide on incentives should also be prepared.

Question 1

Before addressing question #1, it should be re-emphasized that containment is the least desirable method of waste disposal and it would be used only if no other option were available. Also, in the disposal of very hazardous wastes, economics would not play as important a role.

The approaches to ultimate waste disposal will depend on the criteria developed under questions #3 and 4. Other factors to consider would be the volume of the waste, energy consumed in the disposal process, and the economic constraints placed upon the disposal process.

Specific types of pre-processing of the wastes should be investigated, such as incineration, chemical complexing, settling processes, dewatering, and oxidation. Research activities could center around chemical and petroleum plants, etching plants for electronic operations, steel mill pickling operations, and acid mine water renovation facilities.